INTERN EXPERIENCE AT
THE U. S. ARMY ENGINEER WATERWAYS
EXPERIMENT STATION

AN INTERNSHIP REPORT

by

Roger Dale Crowson

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INTERN EXPERIENCE AT

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Approved as to style and content by:

(Chairman of Committee)

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ABSTRACT

Intern Experience at the U. S. Army Engineer
Waterways Experiment Station. (August 1981)
Roger Dale Crowson, B.S., University of Alabama;
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Chairman of Advisory Committee: Dr. Howard L. Furr

This report describes the internship performed at the U. S. Army Engineer Waterways Experiment Station during the period September 1979 through May 1981. The immediate supervisor during the internship period was Mr. J. T. Ballard, and the intern supervisor was Dr. S. A. Kiger.

In order to satisfy the general objectives of the internship, the internee served as principal investigator on a research project to develop a force-pulse generator. Mobile tactical communication systems used by the U. S. Army are housed in a shelter typically mounted on a 2½ ton truck. In a battlefield environment these systems could be subjected to violent transient vibrations from airblast generated by high explosive or nuclear weapons. An understanding of the response of the system is needed so that isolation equipment can be designed for its protection. Since testing under actual field conditions is very expensive and time-consuming, testing under laboratory conditions is desirable. The purpose of this project was to design, fabricate, and prove out a laboratory testing device suitable for subjecting the communication equipment to motions which might be expected under battlefield conditions.

Such a laboratory testing device, the force-pulse generator, was developed and calibrated. During initial tests of selected communication equipment the device, in general, exhibited favorable operating characteristics. However, some additional developmental work remains in the area of cutter tool chatter and pulse train design.

ACKNOWLEDGEMENT

The author's sincere appreciation is extended to those faculty members of Texas A&M University and colleagues at the Waterways Experiment Station for their support and guidance throughout the course of this degree program.

Special thanks are extended to Dr. Howard L. Furr for his interest and helpful counsel during the course work leading to this internship and for his efforts in handling the many details associated with a doctoral program. Also, the writer wishes to express his gratitude to his intern supervisor, Dr. S. A. Kiger, for his encouragement and leadership throughout the internship. Messrs. J. T. Ballard and W. J. Flathau of the Structures Laboratory are gratefully acknowledged for their interest and initiative leading to the actual start of this endeavor. Sincere appreciation is extended to Jewell Rook, Loriece Beall and Gracie Goings for their editorial assistance and suggestions in the preparation of this report.

The experimental data used in this report were part of the study supported by the U. S. Army Ballistic Research Laboratory and the U. S. Army Electronic Research and Development Command.

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LIST OF ABBREVIATIONS

AA	Agbabian Associates, Engineers and Consultants
AF	U. S. Air Force
AN/GRC-103	An Army radio system consisting of a transmitter and a receiver
ANFO	An explosive consisting of ammonium nitrate and fuel oil mixture
AVG	Average value
BRL	U. S. Army Ballistic Research Laboratory
CHAN	Channel
CONUS	Continental United States
Cu	Copper
DA	Department of the Army
DNA	Defense Nuclear Agency
DOD	Department of Defense
ER	Engineer Regulation
ERADCOM	U. S. Army Electronic Research and Development Command
EUD	European Division, U. S. Army Corps of Engineers
FFT	Fast Fourier Transform
FM	Frequency modulation
KT	Kiloton
OCE	Office, Chief of Engineers
Pb	Lead
pC	Picocoulomb
RMS	Root mean square value
SHAPE	Supreme Headquarters Allied Powers, Europe
SL	Structures Laboratory, WES
SMD	Structural Mechanics Division, SL
TD660	An Army multiplexer (part of a communication system)
WES	U. S. Army Engineer Waterways Experiment Station
XMAX	Maximum value
XMIN	Minimum value
Zn	Zinc

CHAPTER 1

INTRODUCTION

OBJECTIVES

The purpose of this report is to establish that the general objectives of the internship, as stated below, have been met:

1. To demonstrate the ability of the internee to carry out all phases of the planning, execution, and reporting of a major engineering task in an organization engaged in areas of extensive engineering concerns. Included in planning activities are cost studies, defining personnel, equipment, and space requirements, and scheduling tasks, and
2. To demonstrate the adaptability of the internee to the structure and approach of a major engineering organization in meeting its objectives, and
3. To demonstrate the value of the program in preparing the internee for a career in a productive engineering organization.

INTERN ORGANIZATION

The internship was spent as a Research Structural Engineer, grades GS-12 and GS-13, in the Structural Mechanics Division (SMD), Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), during the period September 1979 through May 1981. The WES job descriptions for these positions are included in Appendices I(A) and I(B), respectively. The immediate supervisor during the internship period was Mr. J. T. Ballard, Chief, Structural Mechanics Division, and the intern supervisor was Dr. S. A. Kiger, Project Manager.

Brief descriptions of the organizational structure and function of the Corps of Engineers, the Waterways Experiment Station, and the Structures Laboratory are as follows:

U.S. Army Corps of Engineers. The Corps of Engineers, an agency of the Department of the Army, is responsible for a wide range of civil and military missions. The Civil Works mission serves a dual role of developing the nation's water resources while keeping the Engineers ready to respond to national emergencies with state-of-the-art civil engineering. The Civil Works research program is directed toward improving the Corps of Engineers' capability to combine an effective, economical water resources mission and program with environmental safety. In its military mission, the Corps acts as a combat arm of the U. S. Army and as a principal combat support component. Army engineers are also involved in military construction operations for U. S. Army and Air Force personnel. Corps of Engineers research and development funded by military appropriations provide support and technology to meet ever increasing needs of the Army and national security.

The Corps is directed from the Office, Chief of Engineers (OCE), which reports directly to the Secretary of the Army, and is comprised of Boards, Commissions, Engineer Divisions, and Engineer Laboratories. An abbreviated organizational chart of the Corps is provided in Appendix I(C). The WES is the largest of the five Engineer Laboratories.

Waterways Experiment Station. WES is the largest and most diverse of the Corps laboratories, covering over 600 acres at Vicksburg, Mississippi. On a reimbursable basis for the OCE, Corps districts and divisions, and other government agencies, WES performs research in the broad fields of hydraulics, soil and rock mechanics, earthquake engineering, soil dynamics, concrete, expedient construction, nuclear and conventional weapons effects, nuclear and chemical explosives excavation, vehicle mobility, environmental relationships, engineering geology, pavements, protective structures, aquatic plants, water quality, and dredged material.

Research is conducted within a four-laboratory organizational structure with various support groups. An organizational chart of WES and its stated mission are given in Appendices I(D) and I(E), respectively.

Structures Laboratory. As one of the four WES laboratories, the Structures Laboratory is responsible for studying the response of structures to the effects of statically and dynamically induced loads. Emphasis is given to ways to make construction materials, such as concrete, stronger, more durable and more economical. Structures research also concerns the forces created by loading from nuclear and chemical explosions and earthquakes. High explosives are used to simulate nuclear blast and shock effects, while vibratory procedures are employed to simulate earthquake loadings. Extensive laboratory testing capabilities are also available to determine the dynamic properties of earth and related materials under controlled rates of loading and intense states of stress. Mathematical models are formulated to simulate behavior and used to predict structural response and soil-structure interaction. The stated mission and functions of the Structures Laboratory are presented in Appendix I(F).

INTERNSHIP POSITION

In order to meet the general internship objectives while performing the duties assigned, the following specific responsibilities were set forward:

1. Perform literature review pertinent to the specific project assigned.
2. Prepare plans and methods for conducting necessary research into specific problem areas, including:
   a. Scope of work.
   b. Method of approach.
   c. Detailed test plan.
   d. Instrumentation type and layout.
   e. Type data recording.
   f. Method of data analysis.
   g. Method of comparing experimental and analytical results.
3. Prepare detailed financial plans as pertinent to the specific project and/or Division operations, including:
   a. Estimates of project costs.
   b. Capital budgeting proposals, considering cost/benefit ratios, payback periods, present value models, etc.
   c. Methods of more accurate and meaningful cost accounting and cost control records for each project.
   d. Methods for reducing project costs through more efficient operational procedures and labor/equipment utilization.

4. Prepare field-test personnel policies, taking into account work hours, assignment of duties to personnel, safety regulations, performance appraisals, and other management related functions.
5. Perform technical analysis and design as required for specific project, including such items as:
   - a. Develop similitude relations to be used in developing structural models.
   - b. Structural design of steel, reinforced concrete, timber, etc., models for experimental testing.
   - c. Design, or check designs, of auxiliary structures such as support brackets or frames, lifting and hoisting beams, test jigs, etc.
   - d. Finite element analysis of structures under investigation including developing proper geometry of analytical model, proper input parameters, and proper output interpretation.
6. Serve as contracting officer's representative (contract monitor) for work under contract to WES being performed by other agencies or private firms.
7. Serve as WES representative in project meetings with other agencies and interested parties.
8. Prepare proposals of work and present such proposals to interested funding agencies such as Office, Chief of Engineers, and Defense Nuclear Agency.

CHAPTER 2

DEVELOPMENT OF A FORCE-PULSE GENERATOR

THE PROBLEM

Mobile tactical communication systems used by the U. S. Army are housed in a shelter typically mounted on a 2-1/2-ton truck. In a battlefield environment these systems could be subjected to violent transient vibrations from airblast generated by high explosive or nuclear weapons (Figure 1). An understanding of the response of the system is needed so that isolation equipment can be designed for its protection. Since testing under actual field conditions is very expensive and time-consuming, testing under laboratory conditions is desirable. The purpose of this project was to design, fabricate, and prove out a laboratory testing device suitable for subjecting the communication equipment to motions which might be expected under battlefield conditions.

BACKGROUND

Shelters containing the equipment have been tested in events DICE THROW* and MISERS BLUFF*, and the shelters are currently scheduled to be part of the MILL RACE event during 1981. Acceleration of various individual pieces of equipment as well as the equipment racks are typically measured in the field events. Typical acceleration-time histories at the midpoint of the equipment rack, recorded in the DICE THROW event, are shown in Figure 2. Residual shock spectra for the horizontal data record of Figure 2 are shown in Figure 3, from which can be observed the broad frequency range of response (20 to 5000 Hz).

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* DICE THROW was a Defense Nuclear Agency high-explosive field test in which 600 tons of ANFO (500-ton TNT equivalent) was detonated. The airblast from this test was considered to simulate that of a 1 KT nuclear weapon. Various U. S. and foreign laboratories participated in the test which was conducted October 6, 1976, at White Sands Missile Range, New Mexico. MISERS BLUFF was a similar field test in which 120 tons of ANFO (100-ton TNT equivalent) was detonated June 28, 1978, at Planters Ranch, Arizona.

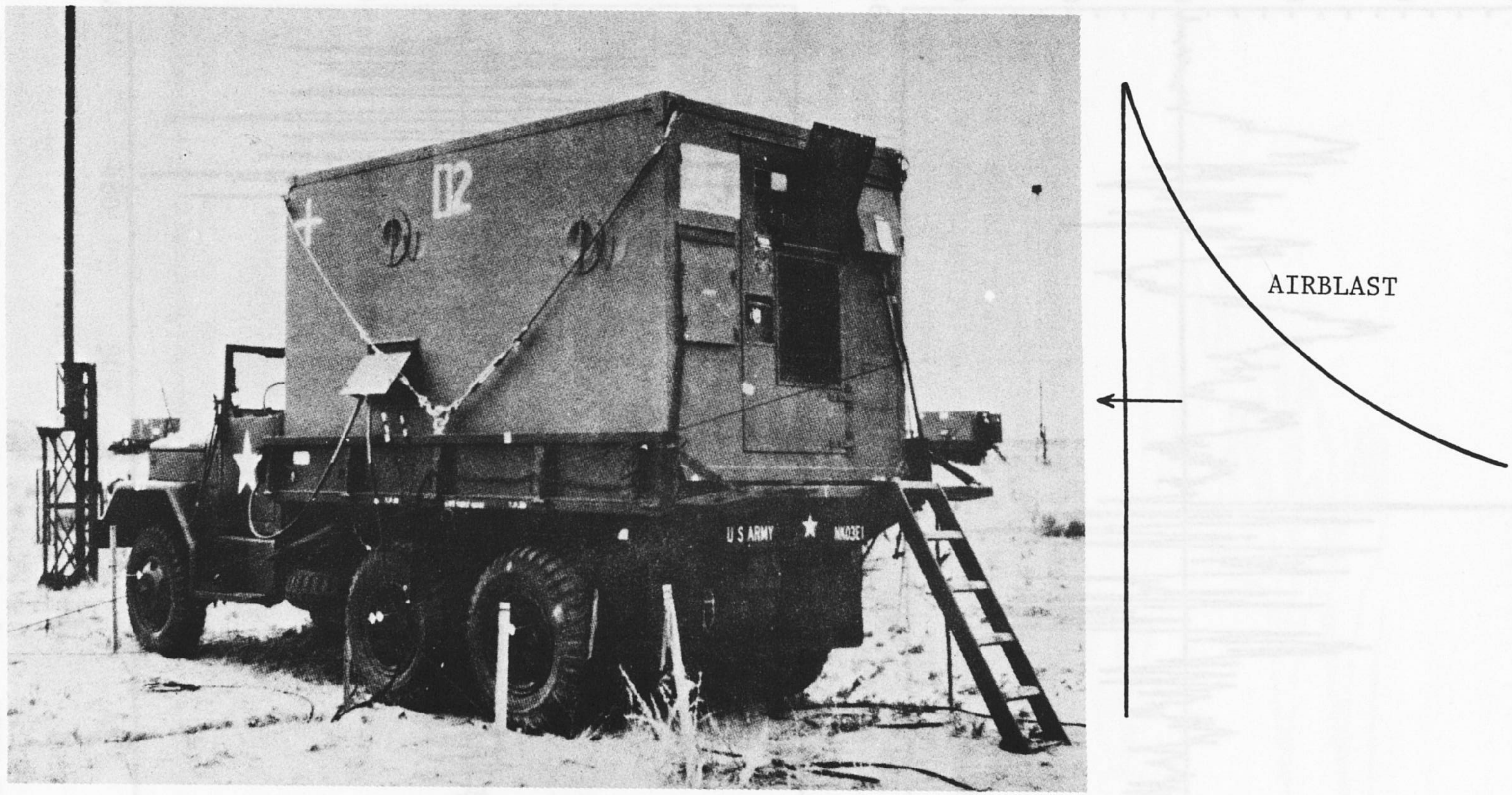


Figure 1. Airblast threat to communications equipment located in shelter mounted on truck

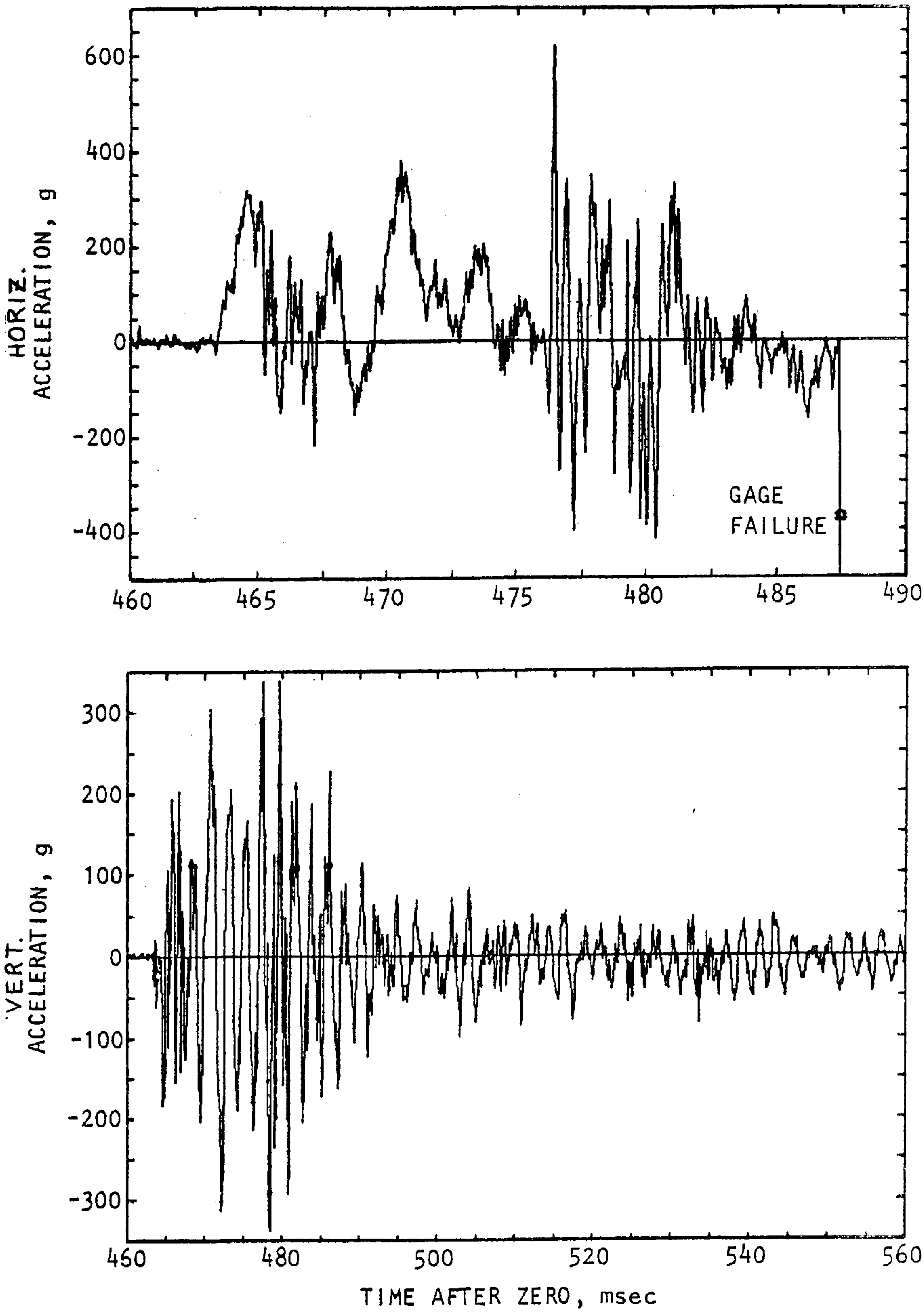


Figure 2. Equipment rack acceleration records from DICE THROW event

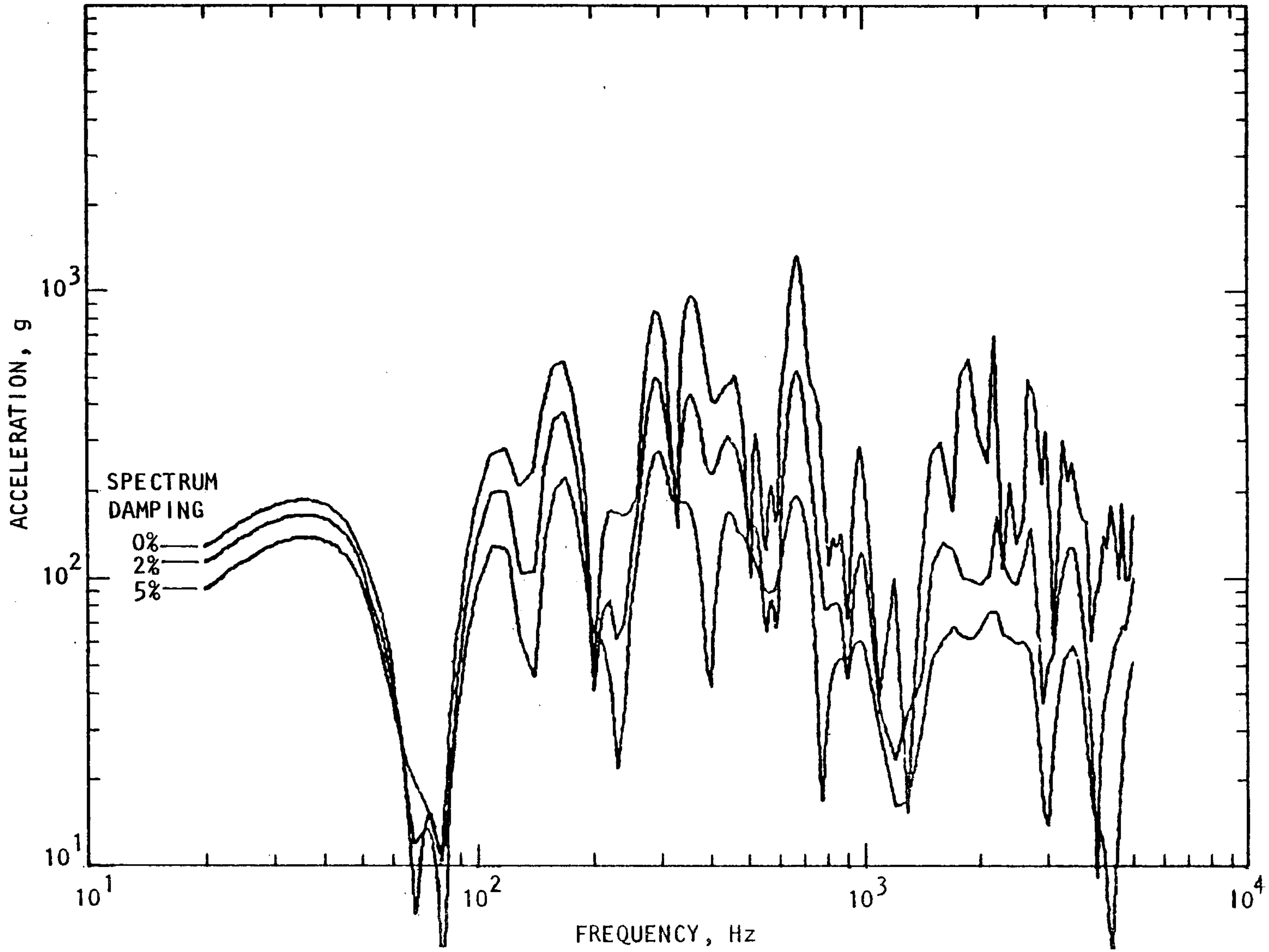


Figure 3. Residual shock spectra of horizontal motion

At zero damping this display is equivalent to the Fourier magnitude of the time history.

The transient loadings and resulting motion of the equipment, as measured in the field events, are quite severe. However, due to the nature of the tests, operational characteristics of the equipment before, during, and after the tests have not been possible to determine.

A laboratory simulation device capable of generating specified force-time histories was developed to provide similar information as acquired in the field tests. Individual pieces of equipment were subjected to similar motions as measured in the actual field events. Such laboratory testing was deemed to be highly desirable in terms of cost-effectiveness and data obtainable and could be used to determine the vulnerability/survivability of the different classes of equipment. This report describes the program that was initiated to develop and test such a simulation device. Program management was provided by the U. S. Army Electronic Research Development Command (ERADCOM) and the U. S. Army Ballistic Research Laboratory (BRL). The development and implementation of the system continues as a joint effort of the WES and Agbabian Associates (AA).

OBJECTIVES

The objectives of the program are to (a) design, fabricate, and calibrate a force pulse generator device; (b) develop pulse trains which will produce equipment motions that match specified criteria; and (c) subject selected communication system components to simulation tests.

RESOURCE REQUIREMENTS

At the request of project sponsors, BRL and ERADCOM, personnel of WES discussed the program with the sponsors and prepared a proposal outlining cost and time estimates. Due to the sponsors' funding structure it was realized that the project would extend over several years and would be divided into basically two phases--pulser development and equipment testing. The original proposal prepared by WES addressed only the first phase--pulser development.

Original Proposal. The objective of Phase I was to develop, calibrate, and demonstrate a programmed force-pulse generator. The project would be a joint effort of WES and AA. To accomplish its tasks WES proposed the following requirements for funds and manpower:

Project Engineer - 4 months	$20,000
Electronic Technician - 2 months	7,000
Engineering Technician - 6 months	15,000
Pulser hardware and fabrication utilizing WES Machinists and Welders	11,000
Data processing and report	5,000
	$58,000

The costs include all laboratory overhead.

For internal planning the project would require a minimum working space of 180 ft^2 within the SMD's laboratory. The space would also have to be in a location so that the laboratory's overhead crane could be utilized.

The project requirements were such that all necessary electronic instrumentation could be obtained from WES supply. Required equipment, the responsibility of the electronic technician, would include 4 accelerometers, two load cells, associated amplifiers, calibration panel, oscilloscope, oscillograph, tape machine, and multimeters. For the type testing done at WES these items generally constitute a standard instrumentation rack.

Revised Proposal. The program outlined in the original proposal was only partially funded the first year and, thus, was not completed. The approach and scope of the project were altered somewhat by the sponsor during the first year and a revised proposal was submitted for the second year funding. The revised proposal included both phases, i.e. pulser development and equipment testing. The testing was to be done at a field test site, rather than at WES, due to restrictions in obtaining the items to be tested. The revised proposal is summarized as follows:

Field tests - 3 months	$180,000
Project Engineer - 6 months	33,000
Electronic Technician - 3 months	10,000
Engineering Technician - 6 months	20,000
Hardware and pulser fabrication	12,000
Data processing and report	20,000
	$275,000
Less previous funds	-60,000
	$215,000

The same WES facilities would be required as in the original proposal and a similar facility would be required for the field tests.

Due to funding limitations the sponsor reduced the scope of the project. The field tests were cancelled and the number of components to be tested were reduced. However, an additional series of tests not previously specified was added to the program. The project was funded $54,000 the second year.

Personnel. Due to personnel shortages at WES during the period of the project, and an unusually heavy workload in the SMD, a full-time engineering technician was not available. Using part-time help (high school work-study students) the internee and the electronic technician essentially conducted the entire project. As the situation demanded, an engineering technician was borrowed on a short term basis.

PROGRAM PLAN

To meet the stated objectives the overall program was divided into seven subsections as listed below:

1. Pulse Generator Design and Fabrication
2. Pulser Calibration
3. Test Facility Design and Tests
4. Impedance Measurements
5. Pulse Train Development
6. Simulation Tests
7. Correlation Analysis and Reporting.

DESIGN OF PULSE GENERATOR AND POWER SUPPLY

The pulse generator used in the program was conceptually designed by AA and fabricated by WES.

Design of Pulse Generator. A pulse generator is a device that produces large force time histories that can be controlled to satisfy multimode system response or drive a system to a specified acceleration level. The concept of a mechanical pulse generator simply reverses a device for energy absorption to obtain a force output of the desired characteristics (References 1 and 2). By drawing a mandrel, i.e., a metal bar having metal projections, through a cutting tool (or vice versa) with suitable motive power (air pressure, hydraulic pressure, explosive force, electrical, or mechanical), a series or a set of force-time histories is generated (References 3 and 4). Reaction at the attached points of the device transmits a force output to the structure under test. Amplitude, duration, and shape of the pulse-time histories are controlled by the relative velocity between the cutting tool and the metal projection of the mandrel, and by the shape of the metal projections on the mandrel. The projections are generally referred to as nubbins.

Large forces may be generated from the device. The force required to cut metal is largely independent of the cutting velocity, and is a function of both the volume of metal chips cut and the specific energy of cutting. The energy absorbed in metal cutting, as given by Reference 1, is:

$$Ft = twdu \tag{1}$$

where F = Force of cutting, lb

t, w, d = Length, depth, and width of cut, respectively, in.

u = Specific energy of cutting, in.-lb/in.^{3}

$u_s = 3 \times 10^5$ in.-lb/in.^{3}, mild steel

$u_{Al} = 1.5 \times 10^5$ in.-lb/in.^{3}, aluminum

Metal-cutting information from the Metals Handbook (Reference 5) generally supports the foregoing information. Higher rake angles, to 20 deg, on the cutting tool tends to reduce cutting force and data scatter. At low cutting speeds aluminum is rate sensitive, with the cutting force changing somewhat exponentially between 40 to 100 ips. It is relatively constant at higher speeds. The handbook gives nominal power requirements for cutting various metals as follows:

Magnesium	0.10 hp/in./min
Aluminum	0.15 "
Copper alloys	0.25 "
Steels	0.80 "

These values may change considerably with hardness and alloy content.

For this pulse generator, the power source is a hydraulic ram that has velocity control via the source pressure and a flow control value. A design drawing of the pulser is shown in Figure 4, and a photograph of the operational device is shown in Figure 5. The maximum force output per pulse is 10,000 lb. The maximum travel of hydraulic ram, which controls the entire pulse train time history duration, is 13 in. and the ram velocity can be varied from 40 to 140 ips.

By using more than one pulse generator, multi-axis excitation of a structure can be accomplished. Biaxial tests are planned under the current program. Two active pulse generators were built for the purpose, in addition to one for a spare, and the power supply was designed to drive two units.

Design of Power Supply. To produce the necessary force and velocity to the cutter, high pressure oil is required to drive the hydraulic cylinders. An existing WES pulse generator used in a previous program was powered by a hydraulic system using an air reservoir and air/hydraulic multiplier. This system is shown in Figure 6, and a schematic is shown in Figure 7. The new system, consisting of two separate pulse generators having a larger force capacity, required a new power supply. Based on requirements of two pulsers having a nominal 10,000 lbf capacity each and 13-in. stroke, a power system utilizing the air/hydraulic concept requires: (a) a 14- to 3-in. air/hydraulic multiplier with a

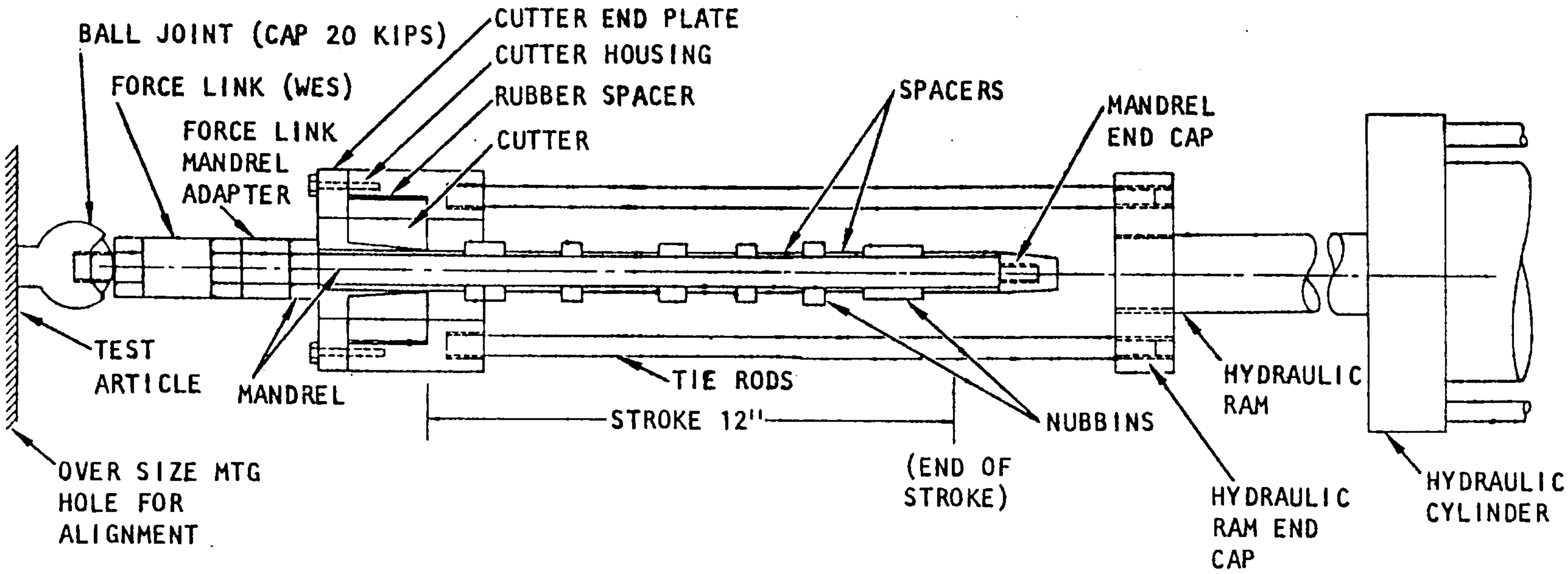


Figure 4. Pulse generator design drawing

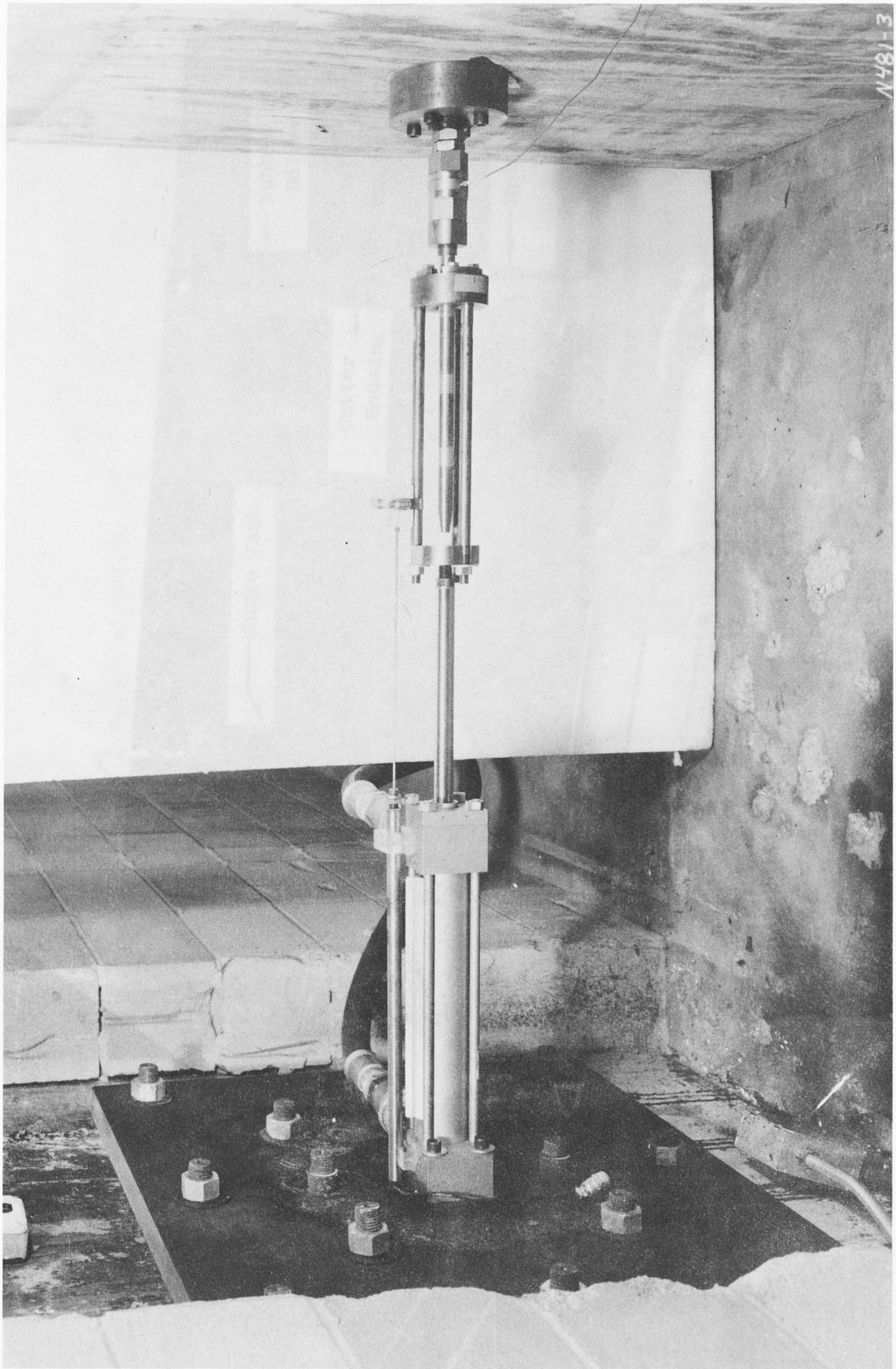


Figure 5. Pulse generator in operational setup

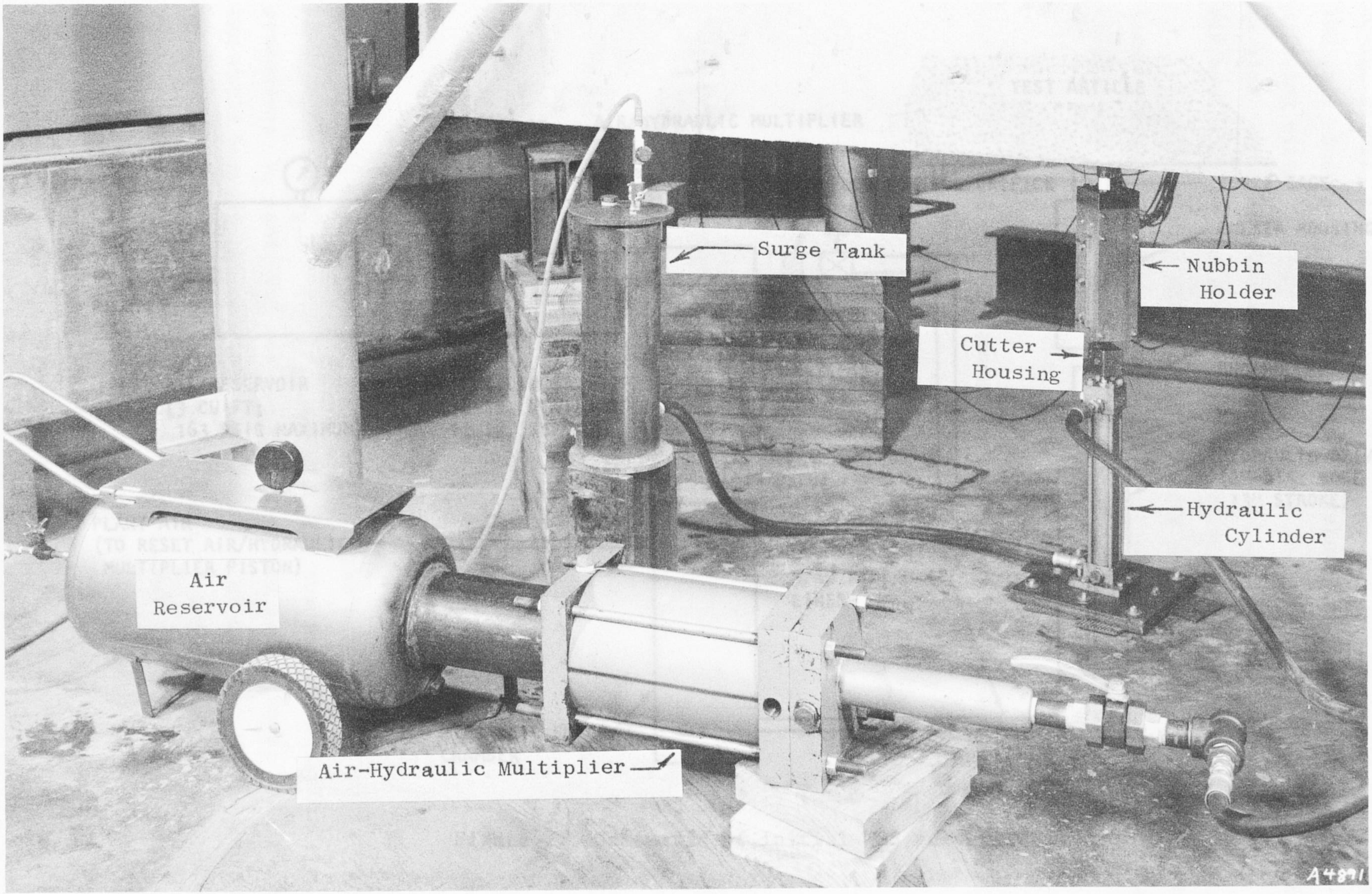


Figure 6. Initial WES pulser utilizing air-hydraulic multiplier in power supply

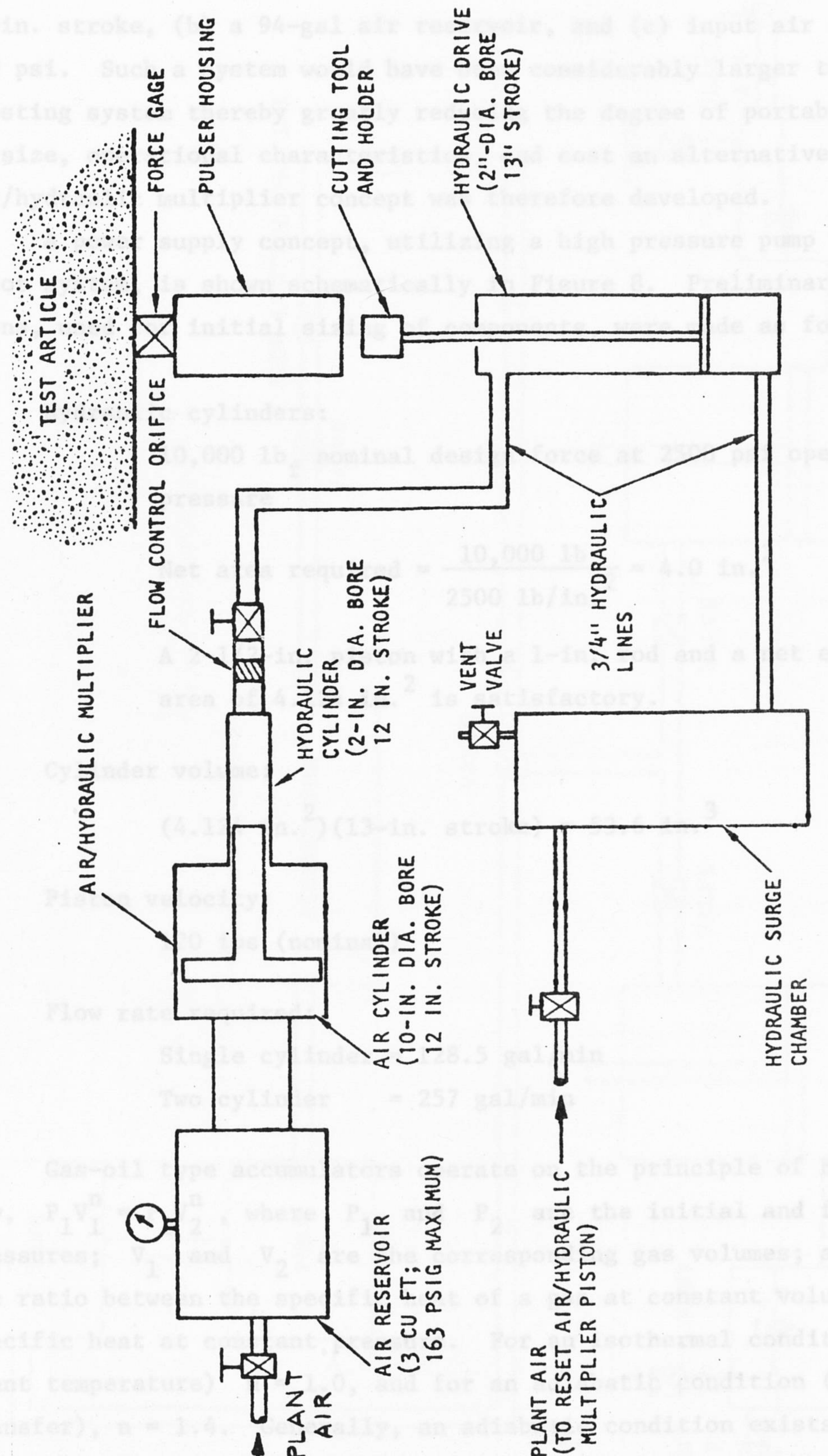


Figure 7. Schematic of initial WES pulser

20-in. stroke, (b) a 94-gal air reservoir, and (c) input air supply of 100 psi. Such a system would have been considerably larger than the existing system thereby greatly reducing the degree of portability. Due to size, operational characteristics, and cost an alternative to the air/hydraulic multiplier concept was therefore developed.

A power supply concept, utilizing a high pressure pump and accumulator system, is shown schematically in Figure 8. Preliminary calculations, used for initial sizing of components, were made as follows:

Hydraulic cylinders:

10,000 lb_f nominal design force at 2500 psi operating pressure

$$\text{Net area required} = \frac{10{,}000 \text{ lb}}{2500 \text{ lb/in.}^2} = 4.0 \text{ in.}^2$$

A 2-1/2-in. piston with a 1-in. rod and a net effective area of 4.124 in.^{2} is satisfactory.

Cylinder volume:

$$(4.124 \text{ in.}^2)(13\text{-in. stroke}) = 53.6 \text{ in.}^3$$

Piston velocity:

120 ips (nominal)

Flow rate required:

Single cylinder = 128.5 gal/min

Two cylinder = 257 gal/min

Gas-oil type accumulators operate on the principle of Boyle's Gas Law, $P_1V_1^n = P_2V_2^n$, where P_1 and P_2 are the initial and final gas pressures; V_1 and V_2 are the corresponding gas volumes; and n is the ratio between the specific heat of a gas at constant volume and its specific heat at constant pressure. For an isothermal condition (constant temperature) $n = 1.0$, and for an adiabatic condition (no heat transfer), $n = 1.4$. Generally, an adiabatic condition exists for rapid (less than one minute) expansion or compression of gas or when insulating materials are used in the accumulator. For sizing an accumulator as

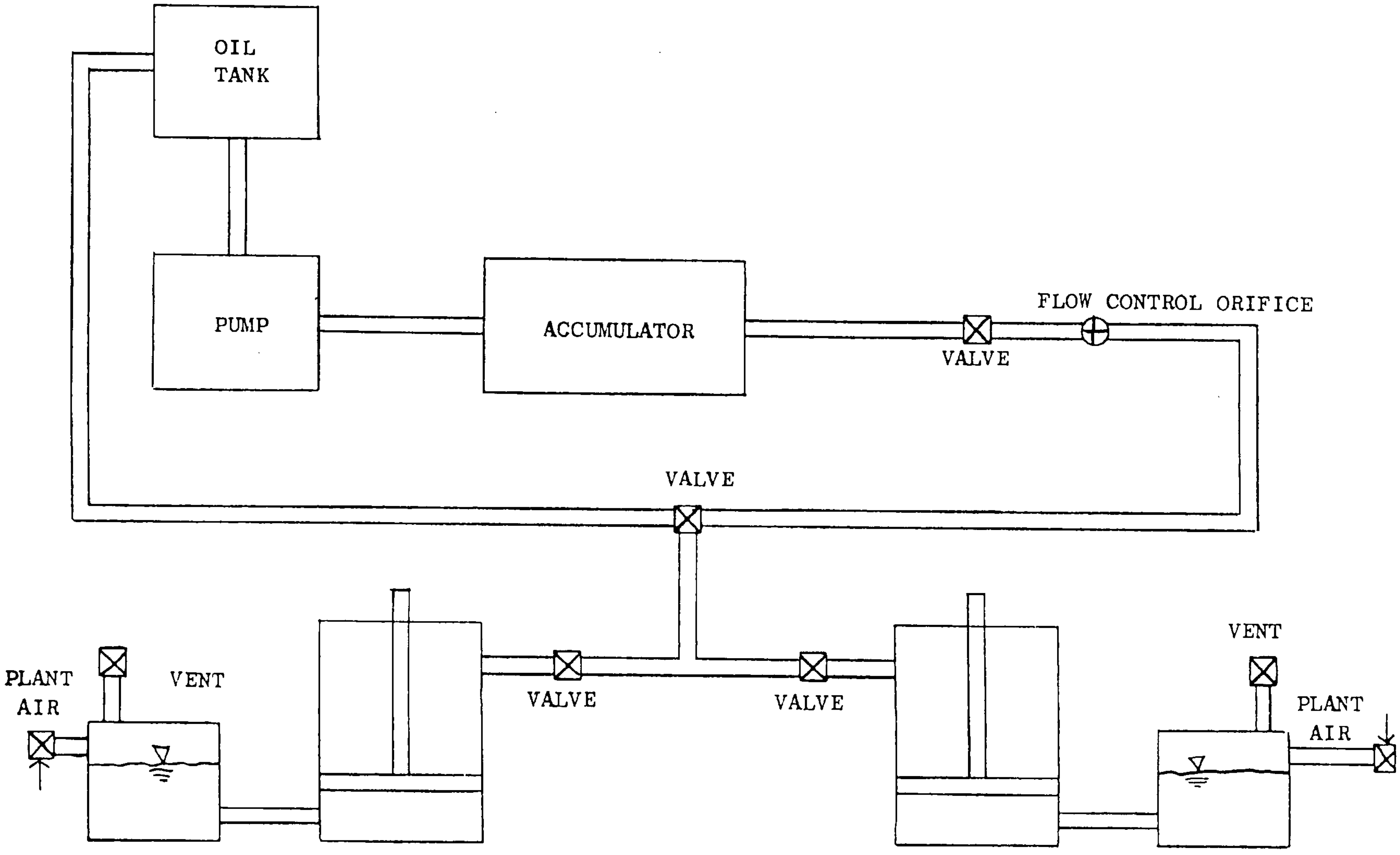
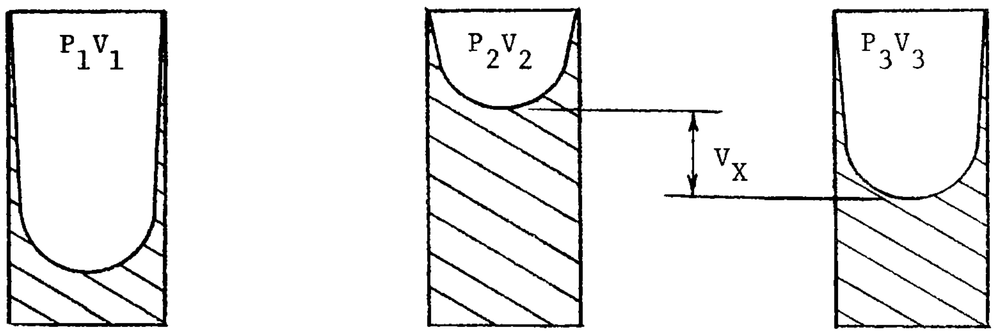


Figure 8. Hydraulic power supply schematic

an auxiliary power source, the amount of fluid required from the accumulator to meet the system needs must be known. The following formula presents a simplified method of determining the capacity of the accumulator to be used (Reference 6, p. a-82):

$$V_1 = \frac{V_x \left[\frac{P_3}{P_1}\right]^{1/n}}{1 - \left[\frac{P_3}{P_2}\right]^{1/n}} \qquad (2)$$



Precharged Fully Charged Discharged

where:

V_1 = Size of accumulator necessary, in.^{3} Maximum volume occupied by gas at precharge pressure.

V_x = Volume of fluid discharged from accumulator, in.^{3}, i.e., additional volume of fluid demanded by the system.

P_1 = Gas precharge of accumulator, psi. Must be less than or equal to minimum system pressure, P_3.

P_2 = Maximum system design operating pressure, psi.

P_3 = Minimum system pressure at which additional volume of fluid is needed, psi.

V_2 = Compressed volume of gas at maximum system pressure, in.^{3}

V_3 = The expended volume of gas at minimum system pressure, in.^{3}

n = 1.4

The maximum precharge pressure, P_1, was limited to that of a standard nitrogen bottle (2200 psi); considering the volume of two cylinders, V_x was taken to be 130 $in.^3$; the required pressure for 10,000-lb force, P_2, was taken to be 10,000 lb/4.124 $in.^2$ = 2424 psi and the minimum system pressure, P_3, was assumed to be 2100 psi. Using these parameters, Equation 2 resulted in a required accumulator volume of approximately 1400 $in.^3$. A 10-gal accumulator, having a volume of 2080 $in.^3$ was selected as optimum.

The final system design is shown schematically in Figure 9, and a list of components is given in Table 1. Final sizing and selection of components and fabrication of the complete power supply were performed by Activation, Inc., under contract to WES. A photograph of the completed power supply is shown in Figure 10.

PULSER CALIBRATION

To correctly determine the necessary ram velocity, nubbin size and arrangement, and actual force output of the system, a pulser calibration program was required. The basic test plan was prepared by AA with WES performing the actual calibrations and making modifications in the plan as needed.

Calibration Test Setup. For accurate force and time duration measurements, the mandrel and force transducer were affixed to a rigid reaction mass (a massive concrete wall). The hydraulic cylinder also was attached to a rigid surface. A schematic and photograph of the test setup are shown in Figures 11 and 12, respectively. Special holding fixtures for attaching the pulser to the reaction masses were fabricated in the WES shop. A closeup view of the mandrel is shown in Figures 13 and 14, which are pretest and posttest photographs. Alignment, so that the mandrel remains concentric with the cutter assembly throughout the full 13-in. stroke, was accomplished by precise initial positioning of attachments and spherical washers at the mandrel attachment point.

Data Acquisition. Time histories of the output force, ram displacement and velocity, along with depths of cut were measured in the calibration tests. Specifications for the force link (and accelerometers which were used in later tests) are given in Table 2. All data

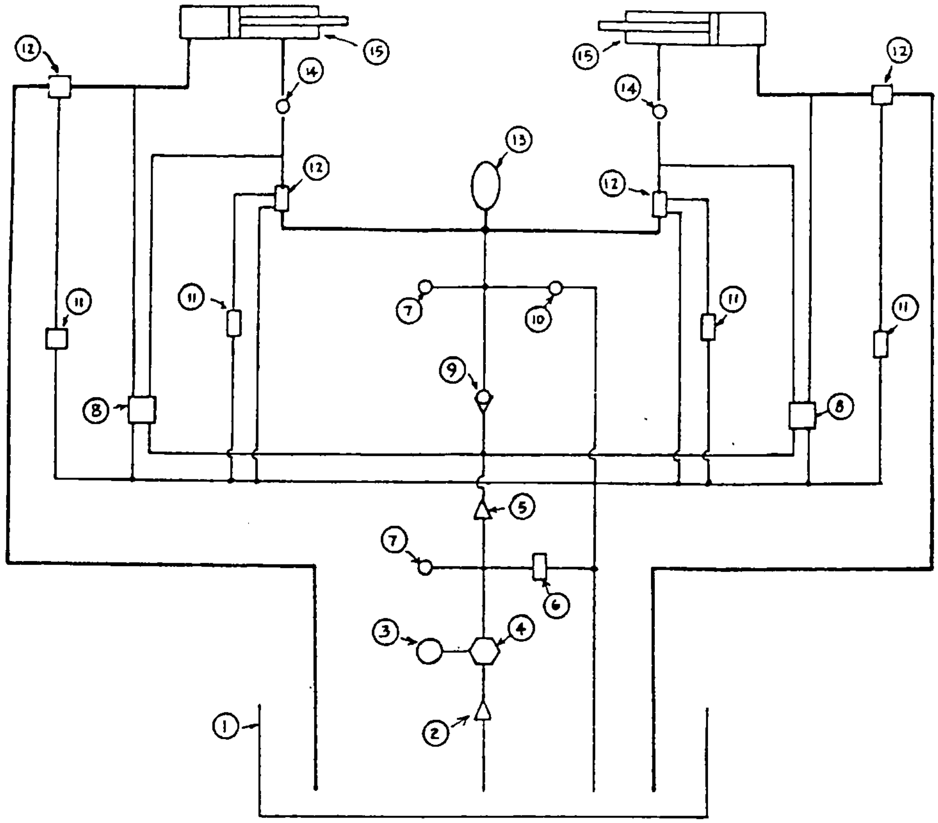


Figure 9. Hydraulic power supply circuit

Table 1. Hydraulic Power Supply Component List

ITEM	QTY	DESCRIPTION	ITEM	QTY	DESCRIPTION
1	1	Thirty-gallon reservoir with cover, sight gage, flush drain, and baffles, Activation No. T30L	9	1	Check valve, Gould No. DC 500
2	1	Suction strainer, MFP No. SR45	10	1	Ball valve, Clayton Mark No. 1/2 CSB-790
3	1	Electric motor, 3HP, Lincoln No. 182T	11	4	Directional control valve, 4-way, 2-position, solenoid operated, Double A No. QJ-005-C-10B1
4	1	Pressure compensated pump, Hydura No. PVQ-06-LSAY-CNSN	12	4	Relief valve, Double A No. BT-12-12A2
5	1	High pressure filter, 5 micron, MFP No. HP1-1-G08	13	1	Ten-gallon accumulator, Greer No. 30A-10A
6	1	Relief valve, sun No. RPGC-JAN-CEB	14	2	Flow control valve, Double A No. YB12-10A1
7	2	Pressure gage, 0-3000 psi, UCC No. UC-3907	15	2	Hydraulic cylinder, 2-1/2-in bore, 1-in rod diameter, 13-in stroke, Sheffer Heavy Duty HH Series Model No. 2-1/2 HHRF13CRA
8	2	Directional control valve, 4-way, 3-position, solenoid operated, Double A No. QF-01-C-10F1			

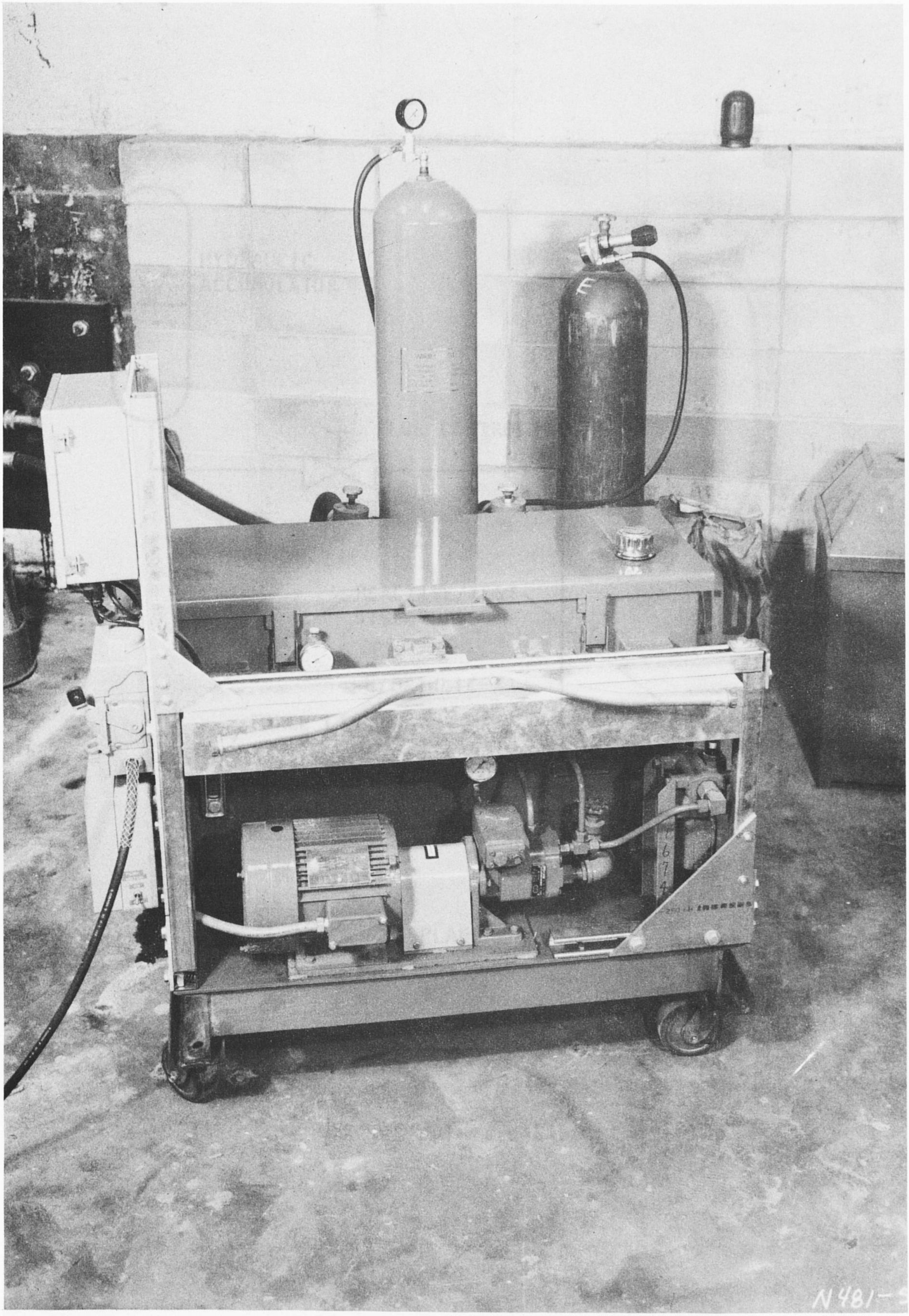


Figure 10. Completed power supply

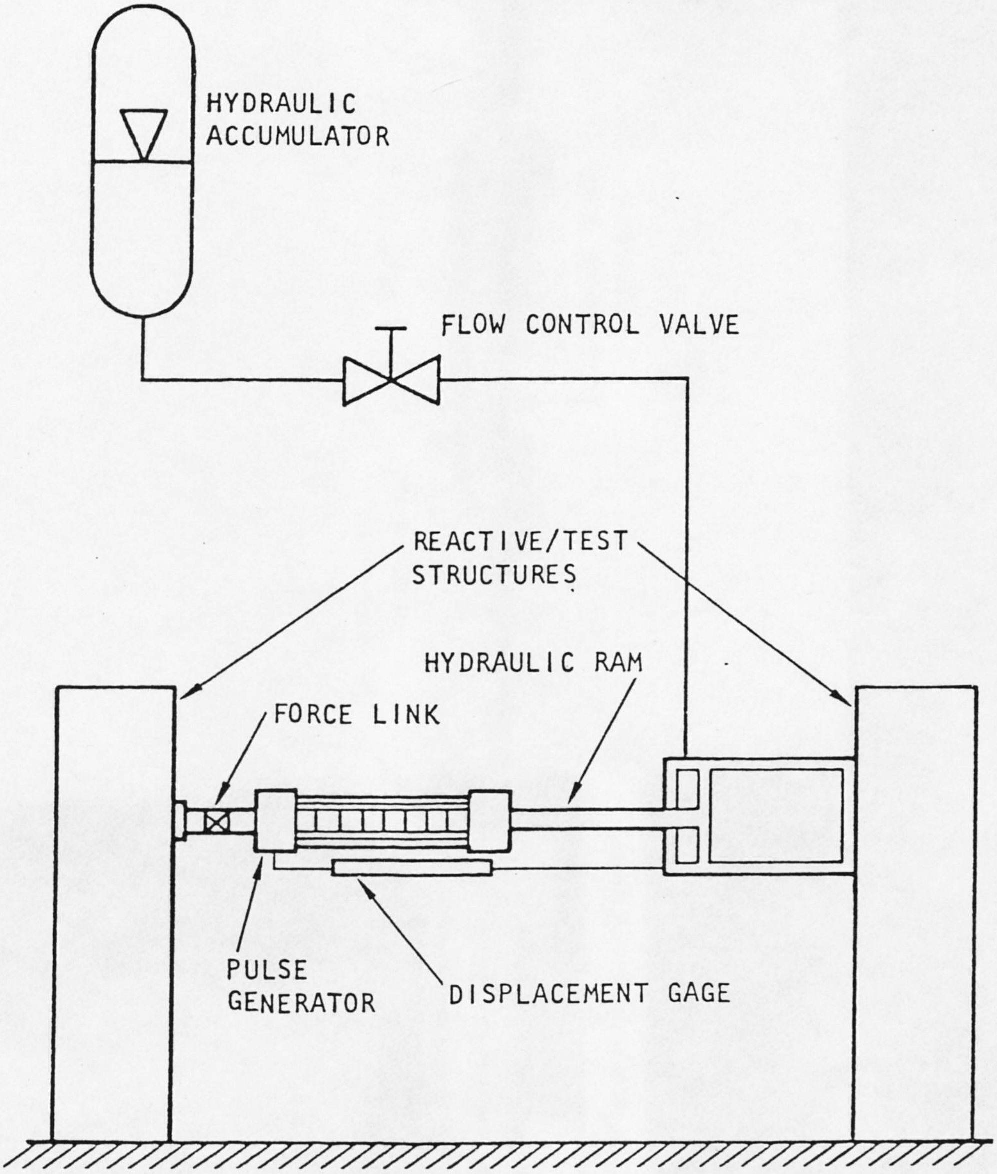


Figure 11. Schematic of pulser calibration setup

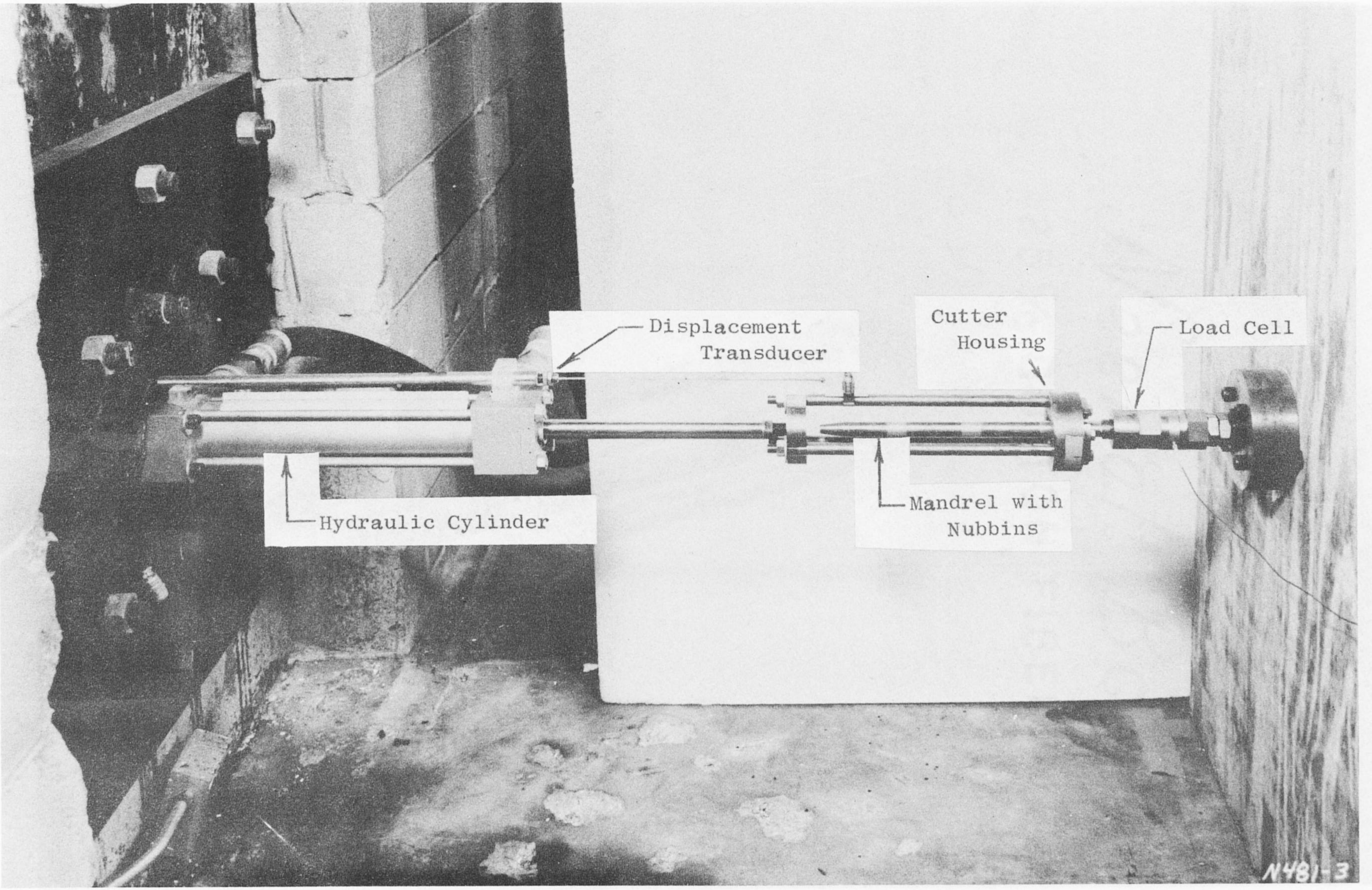


Figure 12. Pulse generator as used in calibration tests

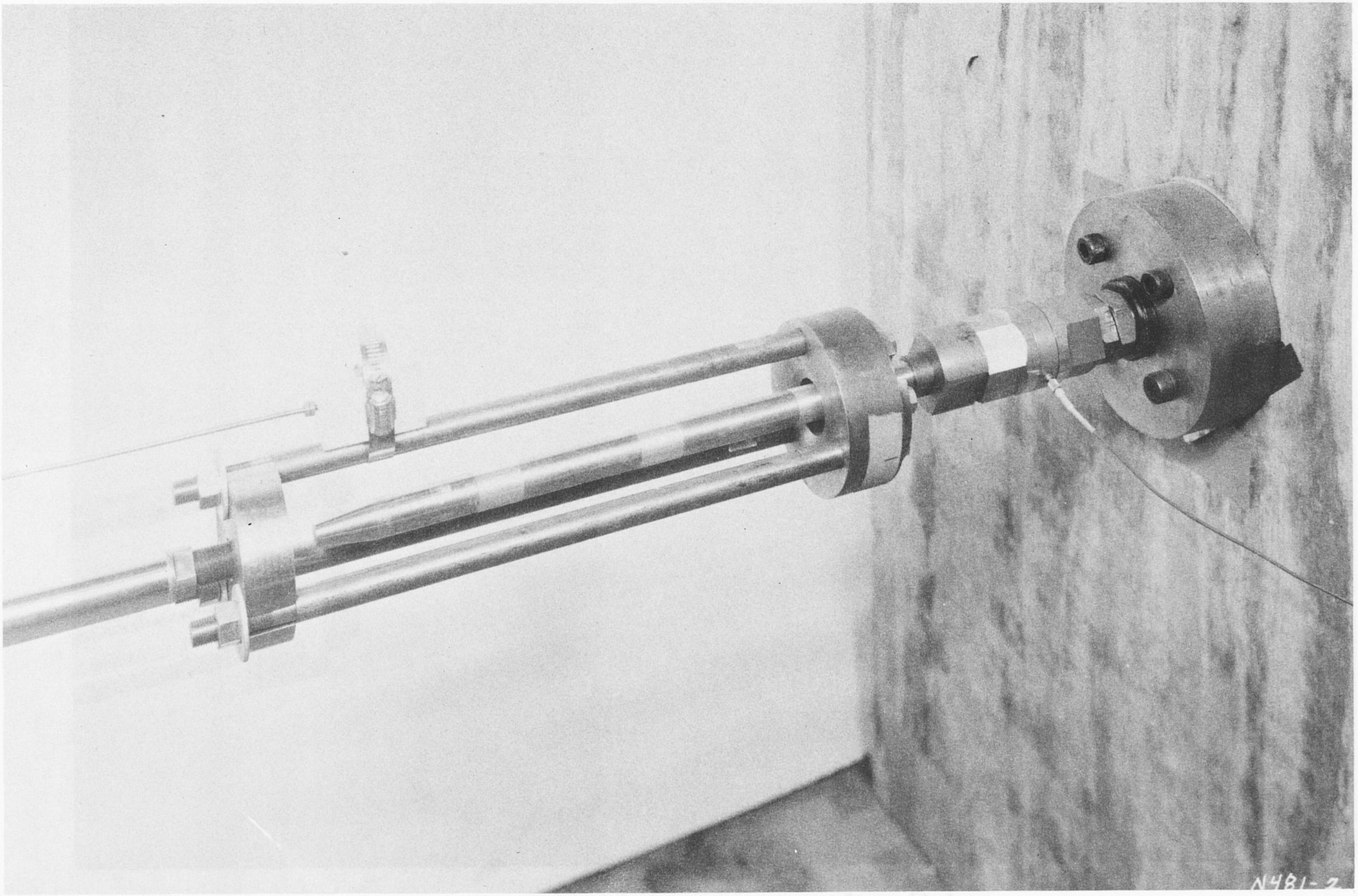


Figure 13: Pulse generator prior to firing

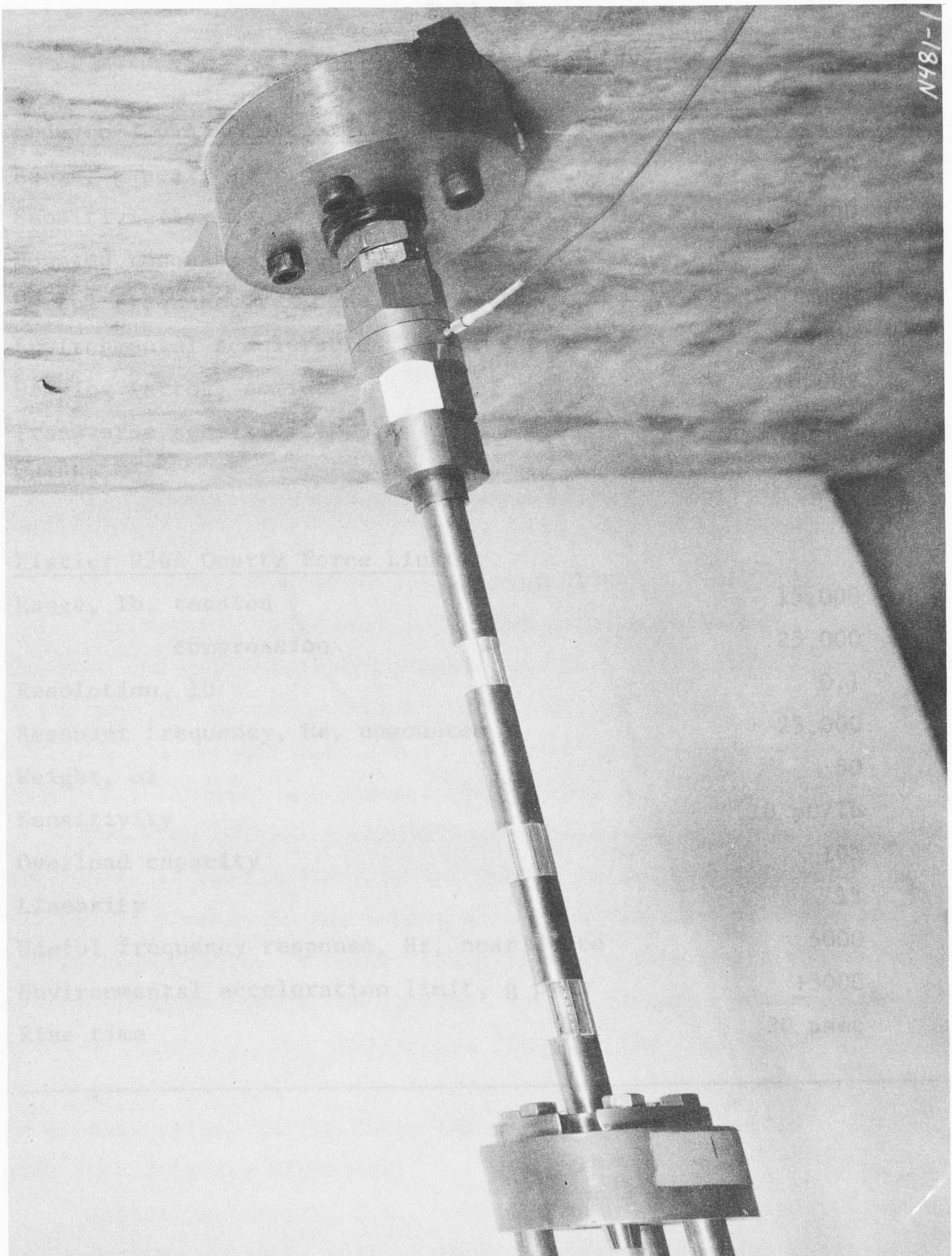


Figure 14. Pulse generator after firing

Table 2

Transducer Specifications

Endevco 2264A Accelerometer:	Specifications
Range, g peak	±2000
Sensitivitity, mV/g at 10 Vdc, nominal	0.250
Mounted resonance frequency, Hz	30,000
Useful frequency response, Hz, dc to	5000
Environmental acceleration limit, g peak	±5000
Damping factor, nominal	0.002
Transverse sensitivity	5%, max
Weight, oz	0.05
Kistler 936A Quartz Force Link:	
Range, lb, tension	15,000
compression	25,000
Resolution, lb	0.1
Resonant frequency, Hz, unmounted	25,000
Weight, oz	50
Sensitivity	10 pC/lb
Overload capacity	10%
Linearity	1%
Useful frequency response, Hz, near dc to	5000
Environmental acceleration limit, g peak	±5000
Rise time	20 μsec

were recorded on FM magnetic tape and played back on oscillograph paper for analysis. Measurements of the depths of cut were made with micrometers taking an average of three readings. Velocities were determined by using the known lengths of nubbins and spacers and actual time as recorded on the oscillograph with a timing reference signal.

Pulser Calibration Tests. The pulse train array, as presented in the basic test plan, is shown in Figure 15. Various combinations of nubbin size and spacing were utilized to determine repeatibility of the pulser and the relationships among:

1. Output force
2. Depth of cut
3. Flow rate and flow control setting
4. Velocity
5. Optimal system operating pressures

Calibration tests were performed using nubbins made from 2024-T3 aluminum and half-hard, free-machining brass alloy 360 (3 percent Pb, 36 percent Zn, 61 percent Cu). Depths of cut ranged from 0.006 to 0.057 in. A typical data record is shown in Figure 16 and the data from Group II tests are summarized in Table 3.

The high frequency damped harmonics in the force time history are the result of tool chatter as the nubbin is cut. Evidence of this chatter is present in the nubbin as the cut surface is rough and dimpled rather than smooth. A cutter shape having a rake angle was tried as a modification to reduce the chatter, but it actually worsened the problem. As to be expected, the chatter was less for the smaller depths of cut and it was somewhat less for the brass material. The chatter was analyzed in greater detail during later tests of the communication equipment when that data was digitized.

System parameters, i.e., nubbin size and arrangement, flow rate, and operating pressure were altered in order to produce calibration curves, such as those shown in Figures 17-21. For the force versus depth of cut curve, the average force for each of the three nubbins and for several flow rates is plotted in Figure 17, and as expected, force is a quasi-linear function of the depth of cut.

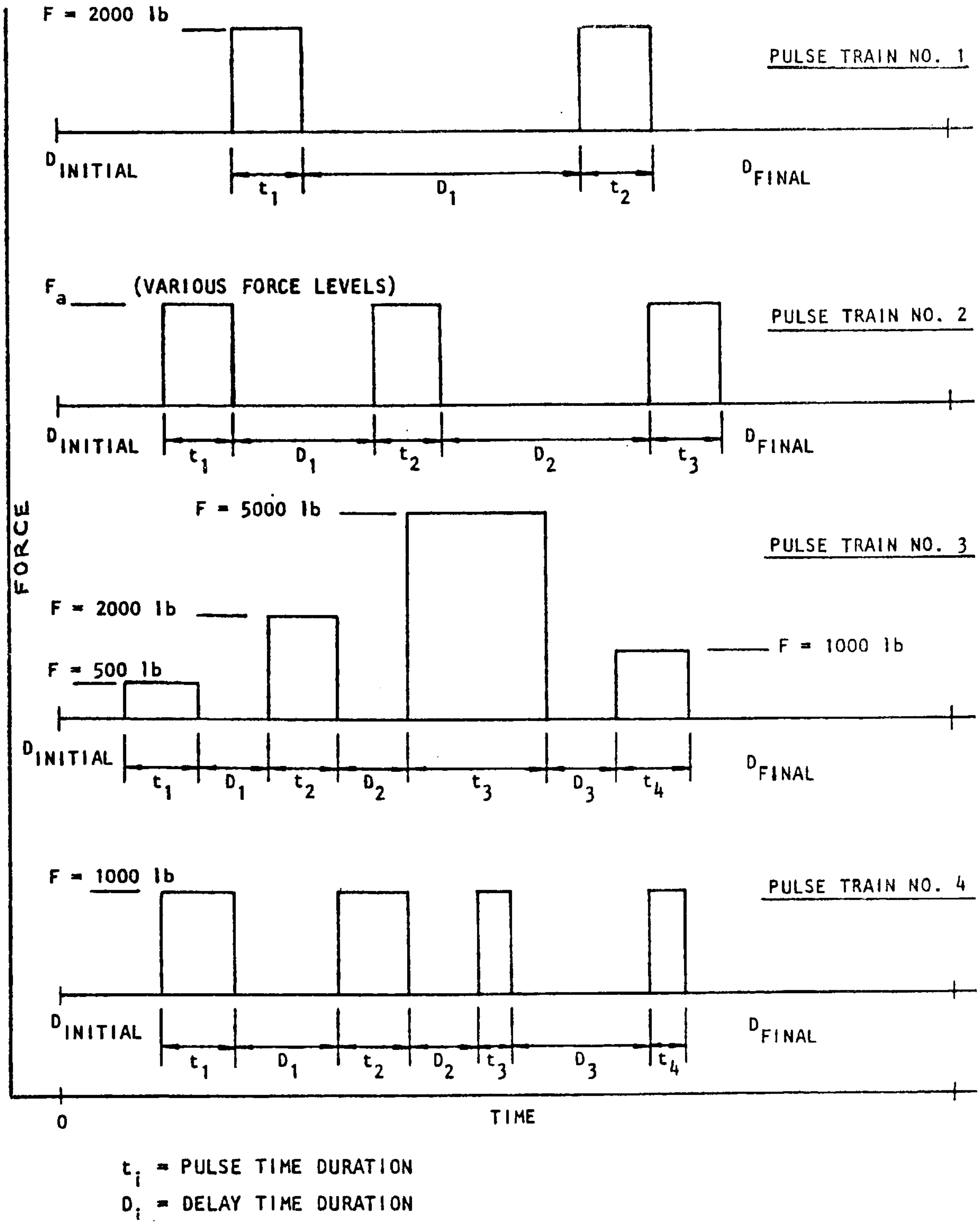


Figure 15. Pulse train array for calibration tests

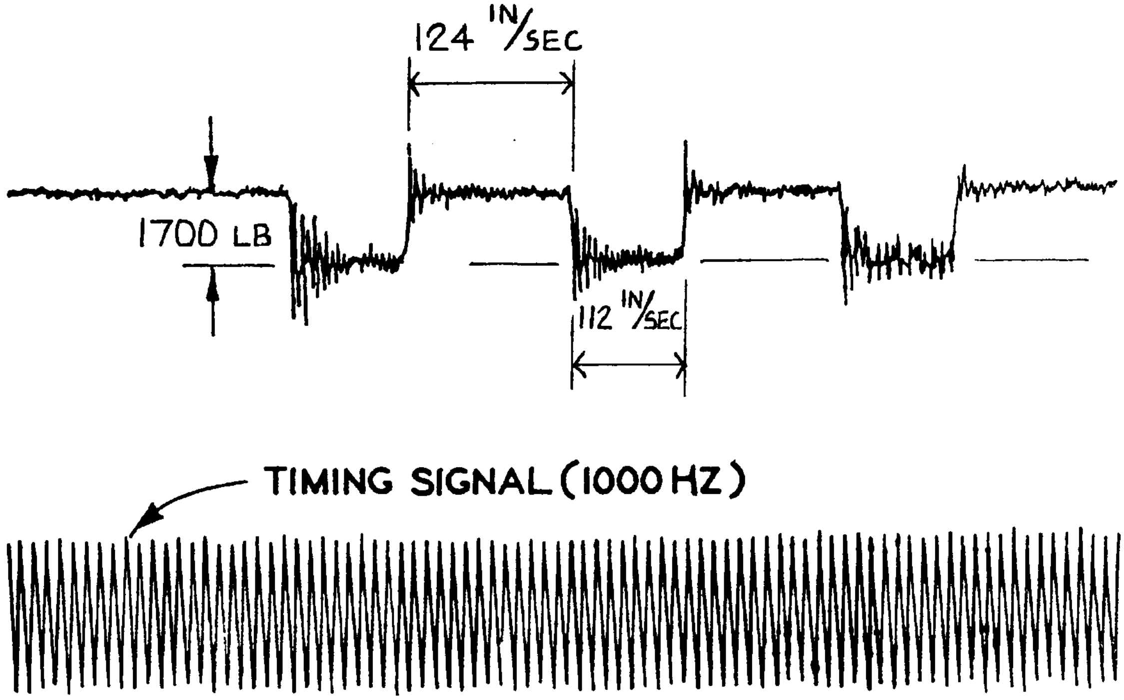


Figure 16. Typical calibration data record

Table 3

Calibration Summary

Test No.	Depth of Cut, in.	(WES Group II Data Logs) 1st Nubbin Force, lbf	1st Nubbin V_1^* in./s	Dwell V_2 in./s	2nd Nubbin Force, lbf	2nd Nubbin V_3 in./s	Dwell V_4 in./s	3d Nubbin Force, lbf	3d Nubbin V_5 in./s	Flow Turns	Average Force, lbf
2E-1	0.006	1700	50	62	1700	48	62	1800	48	8	
2E-2	0.006	1600	105	113	1700	104	112	1700	103	7	F_{av} = 1700
2E-3	0.006	1700	104	109	1700	98	107	1700	100	7	
2E-4	0.006	1700	108	125	1700	112	125	1700	111	6-1/2	
2E-5	0.0055	1700	111	128	1700	119	135	1700	118	6	F_{av} = 1700
2E-6	0.0055	1700	111	132	1700	123	139	1700	125	5-1/2	
2G-5	0.0085	2050	111	131	1950	114	130	2050	111	5-1/2	
2G-6	0.008	2050	108	127	2050	115	128	2050	110	6	
2G-7	0.0085	2050	109	125	2050	115	128	2050	111	6	F_{av} = 2040
2G-8	0.0085	2050	109	123	2050	109	123	2050	106	6-1/2	
2G-9	0.0087	2050	106	125	2050	106	125	2050	103	6-1/2	
2G-10	0.009	2200	91	108	2200	87	109	2200	87	7	
2F-1	0.014	2650	108	135	2650	118	139	2800	118	5-1/2	
2F-2	0.014	2750	108	132	2600	118	134	2750	112	6	F_{av} = 2765
2F-3	0.014	2800	102	123	2800	102	125	2800	100	6-1/2	
2F-4	0.014	2850	88	111	2850	81	111	2850	83	7	
2G-1	0.025	4000	83	111	4000	83	111	4000	80	7	
2G-2	0.025	3900	100	123	3900	102	123	3400	94	6-1/2	F_{av} = 3890
2G-3	0.025	3900	105	127	3900	111	129	3900	108	6	
2G-4	0.025	4000	111	130	3850	111	133	3900	111	5-1/2	
2F-8	0.057	7400	81	133	7400	86	134	7400	86	5-1/2	
2F-9	0.057	7500	81	128	7500	81	131	7500	78	6	
2F-10	0.0565	7800	74	127	7800	68	130	rotated	-	6-1/2	F_{av} = 7620
2F-11	0.0565	7600	66	127	7600	65	130	7600	65	6-1/2	
2F-12	0.0565	5000	76	133	5500	65	134	5500	72	6-1/2	
2F-13	0.0565	7700	65	127	7700	65	127	7850	59	6-1/2	

* Velocity

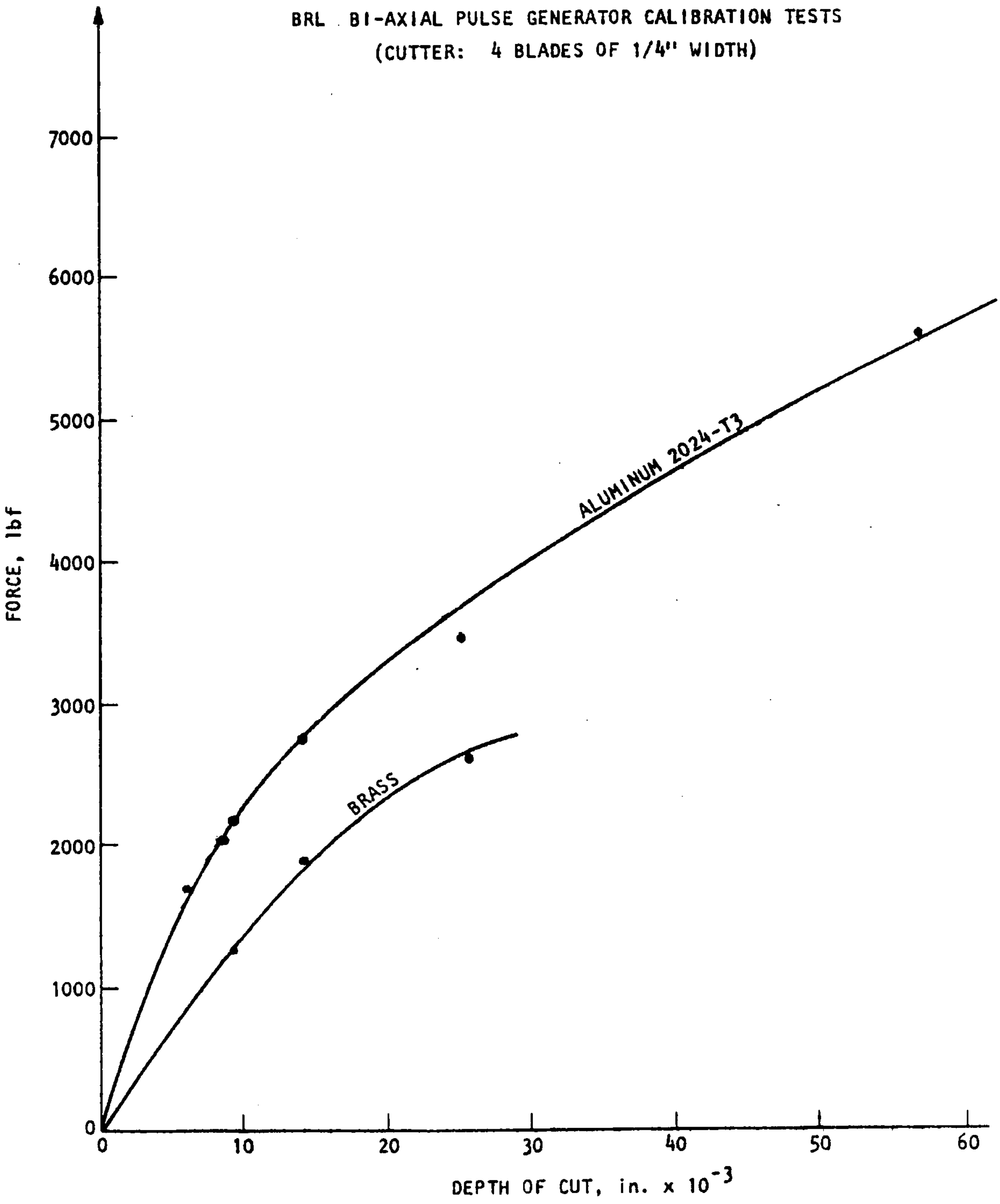


Figure 17. Force versus depth of cut for aluminum 2024-T3 and brass alloy 360

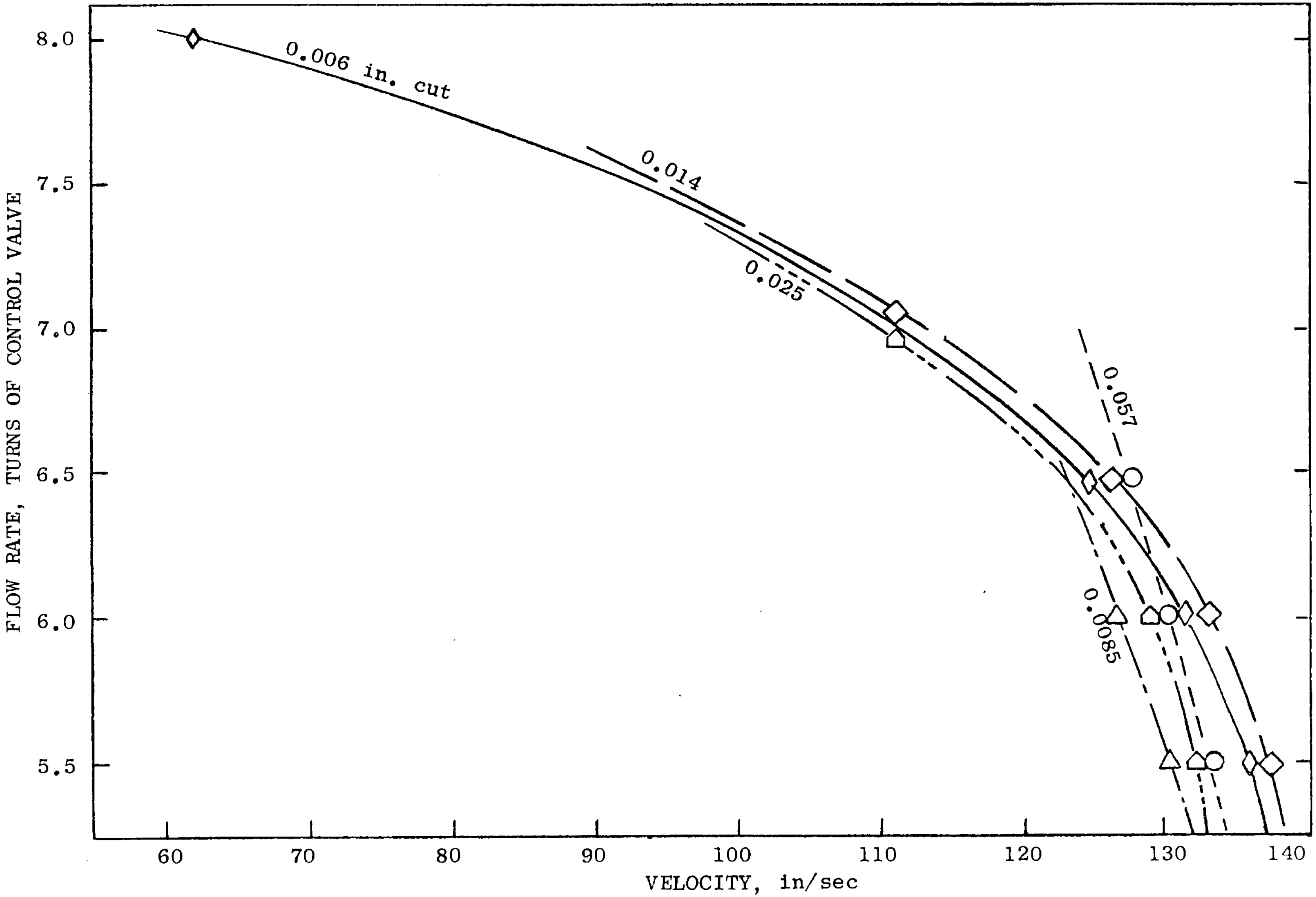


Figure 18. Flow rate versus dwell velocity for specific depths of cut (no load)

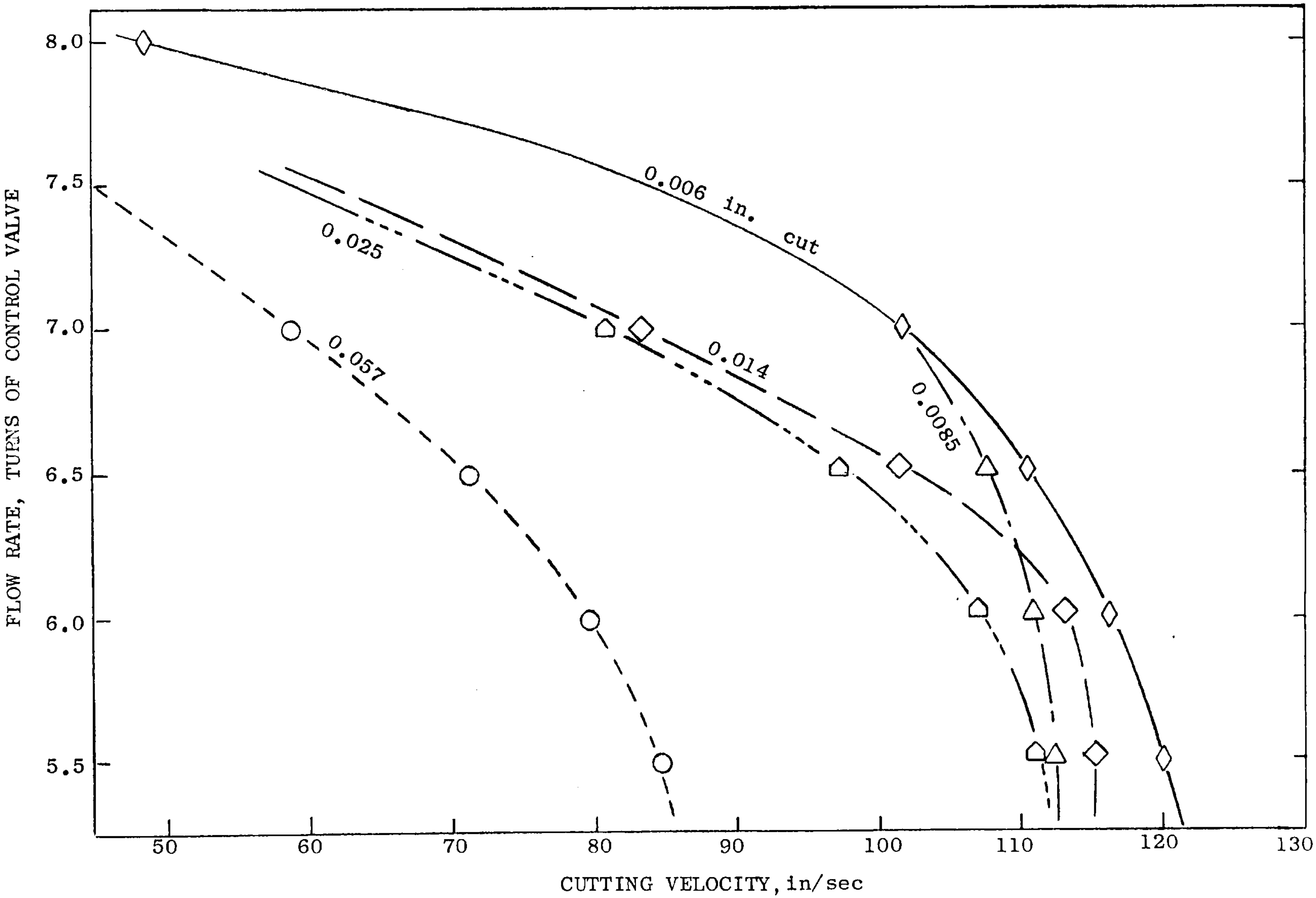


Figure 19. Flow rate versus cutting velocity

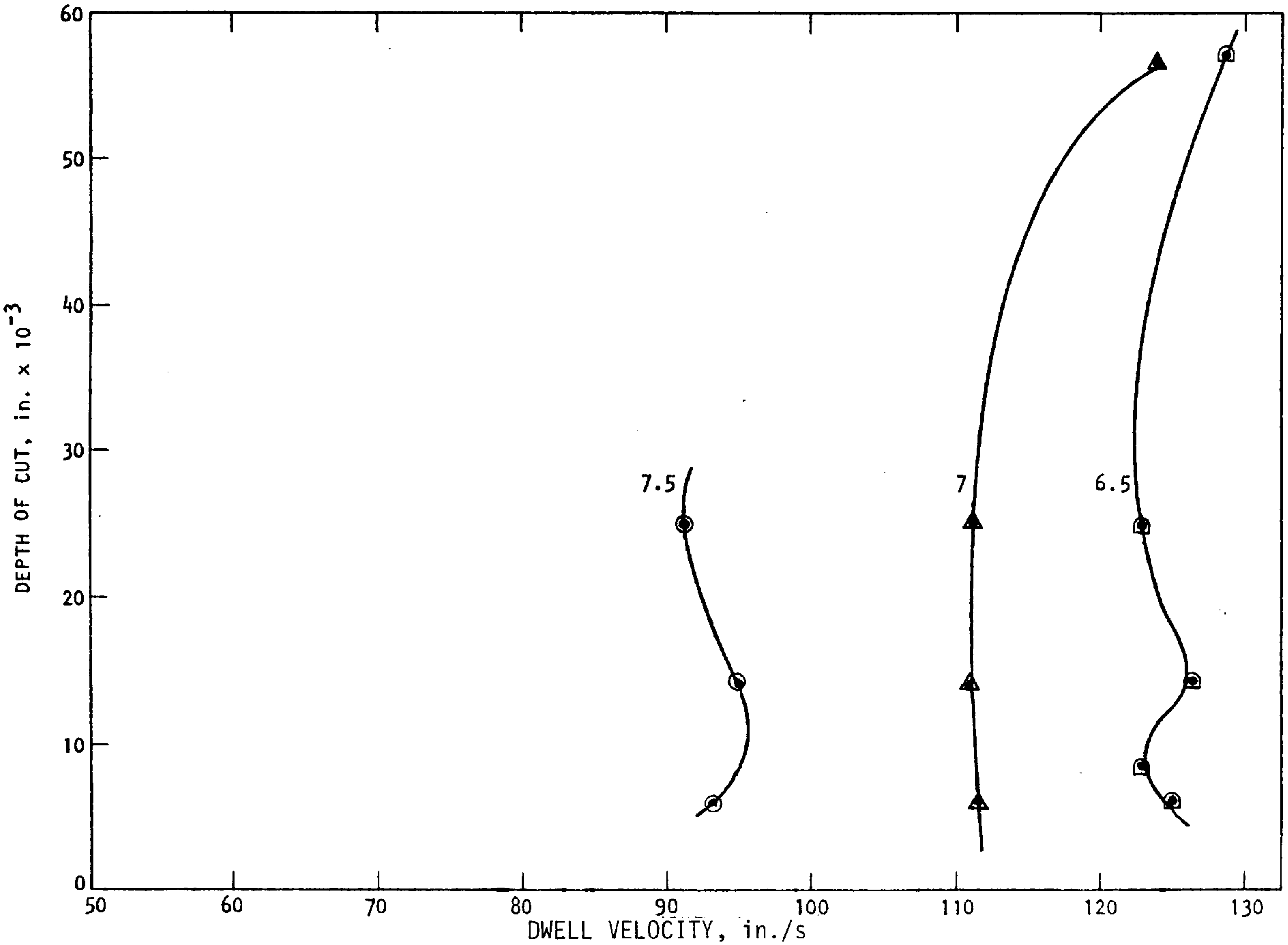


Figure 20. Depth of cut versus dwell velocity for specific flow rates

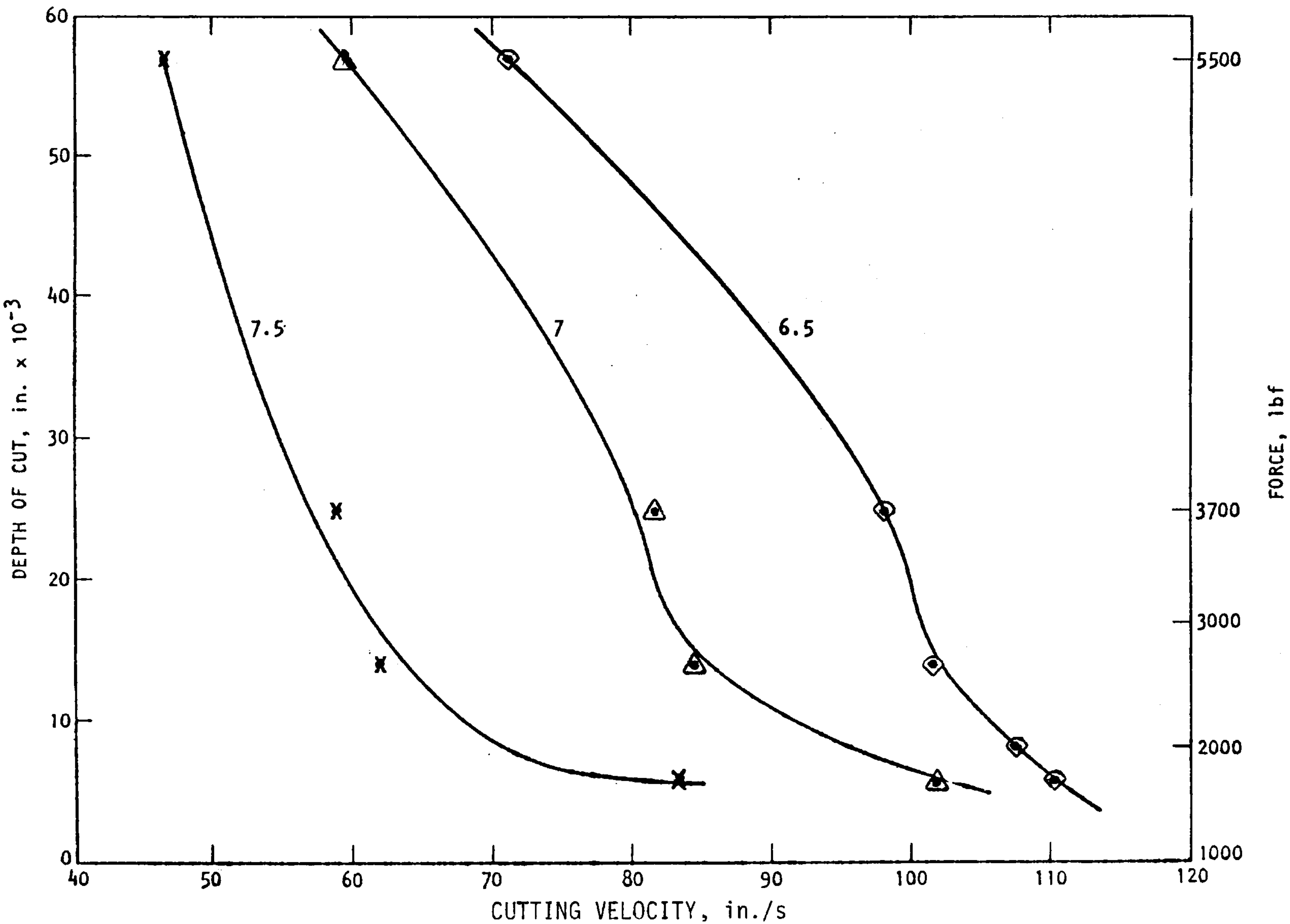


Figure 21. Depth of cut versus cutting velocity for specific flow rates

Velocity versus flow rate index (number of turns the flow control valve was opened) is shown in Figures 18 and 19. The curves in Figure 18 are for the velocity in the dwell region (space between nubbins), thus no load is acting on the cutter. These curves show that the depth of cut for the nubbin immediately preceeding a spacer has very little effect on the velocity across the spacer, i.e. velocity is primarily dependent on flow rate. However, the curves of Figure 19 indicate that the velocity during the cut of the nubbin is dependent upon both the depth of cut as well as flow rate.

The curves in Figure 20, made for three separate flow rates, also indicate that the velocity across the spacers is basically independent of the depth of cut in the nubbin immediately preceeding a spacer. However, the data shown in Figure 21 relate the cutting velocity to both depth of cut and flow rate.

TEST FACILITY DESIGN AND FACILITY TESTS

By agreement between WES and AA, WES designed, fabricated, installed, and tested the facility in which the communication equipment would be tested. The facility consisted of (a) an equipment rack system to house the communication gear under test, (b) reaction structures for the pulse generators in both horizontal and vertical directions, (c) required mounting fixtures for pulse transmission and support, and (d) the pulse generators themselves.

Test Facility. The test facility is shown schematically in Figure 22 and photographs are shown in Figures 23 and 24. A standard equipment rack was furnished by the sponsor, BRL. This rack, constructed of 1-in.-aluminum box tubing and 3/16-in.-aluminum plate, was reduced in height to approximately 3 ft so that the total height of the system with vertical pulser attached would be less than 8 ft. To accommodate the largest pieces of radio equipment, maximum shelf spacing was not altered in the modified rack. Steel reaction structures, to which the pulsers were attached, were designed and fabricated. A loading yoke arrangement was utilized for attaching the pulsers to the equipment rack. The loading yokes were fabricated from 3/4-in.-steel box tubing and attached to the rack with three 3/8-in. bolts at four locations.

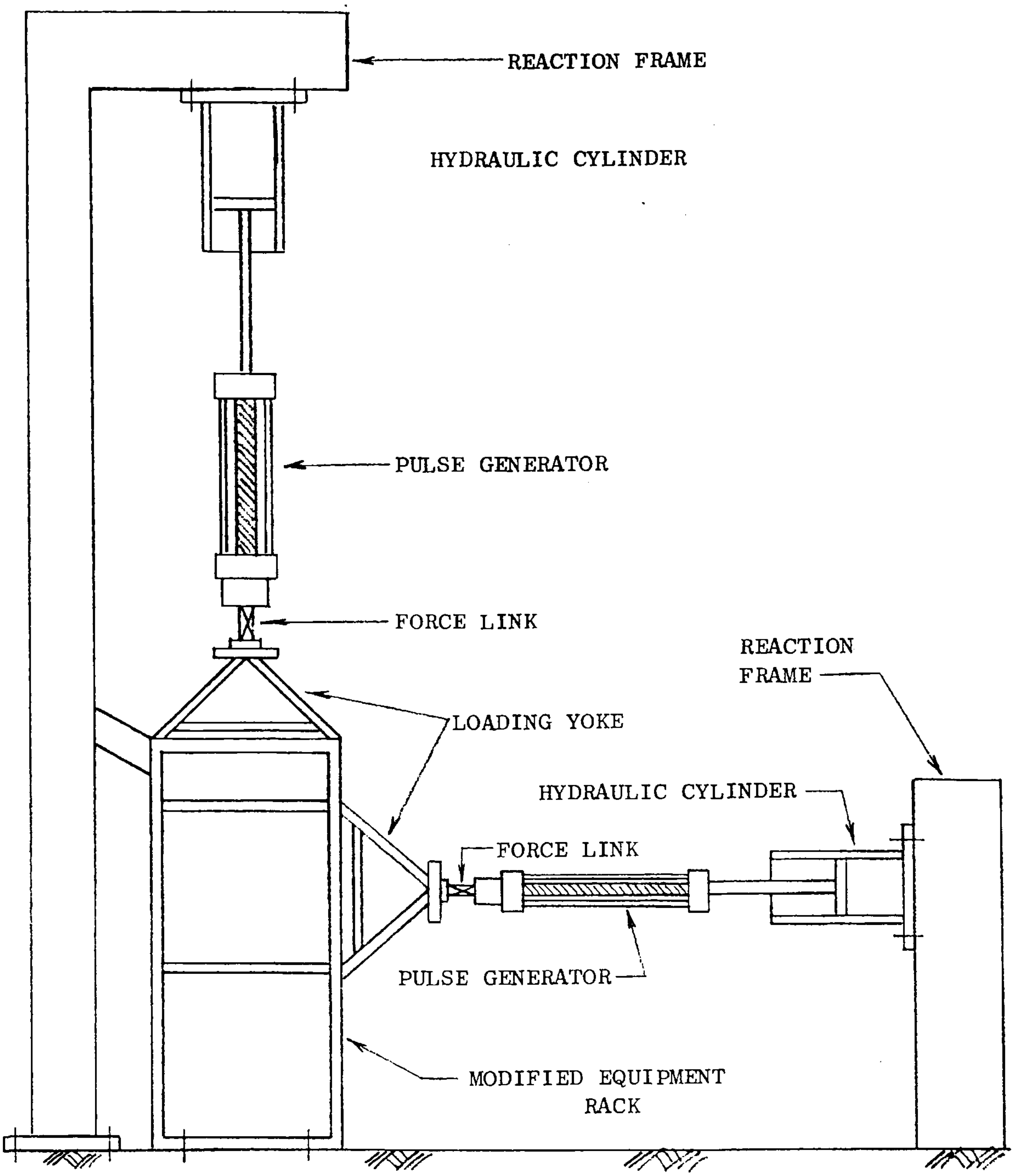


Figure 22. Schematic of biaxial test facility

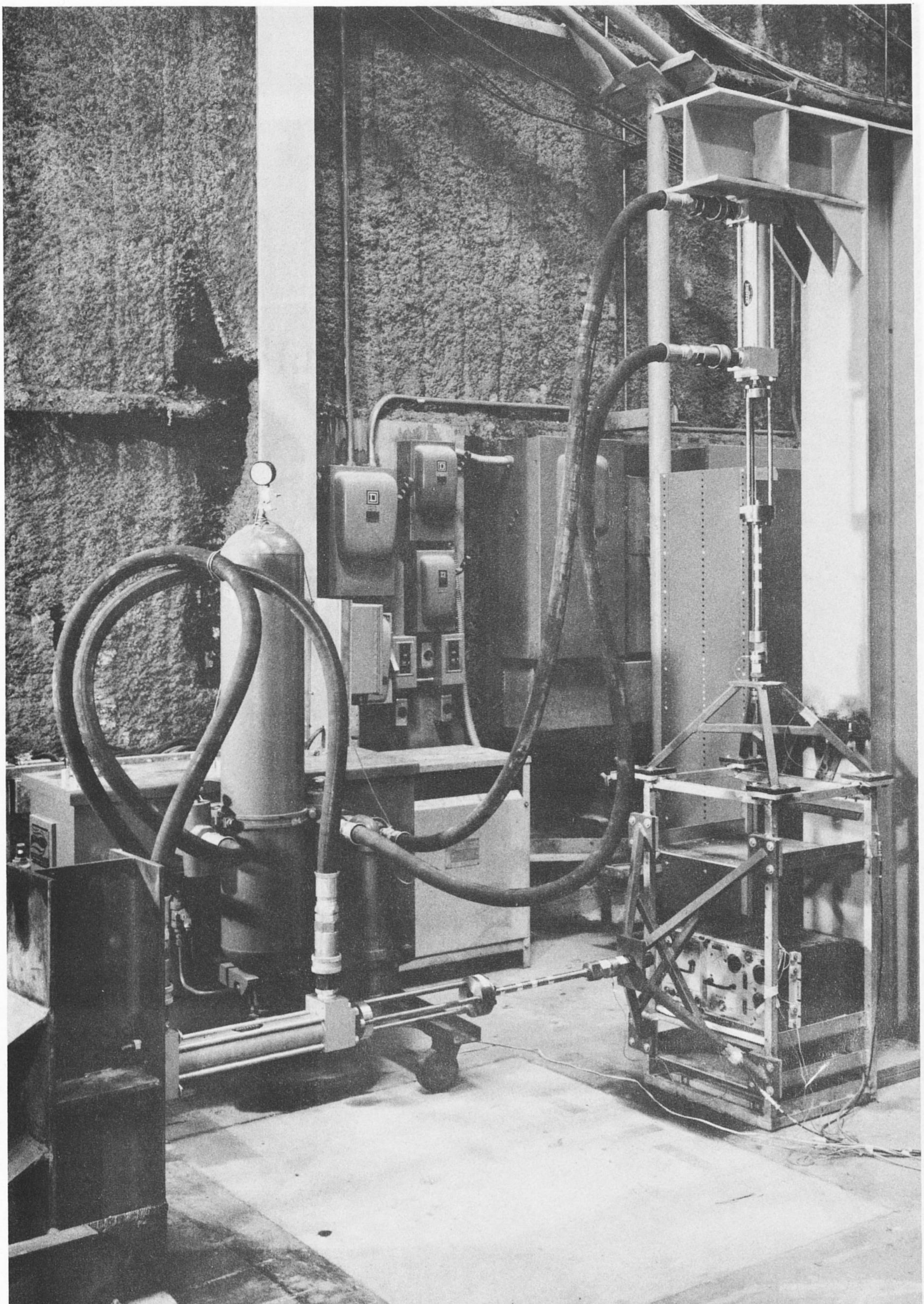


Figure 23. Biaxial test facility (overall view)

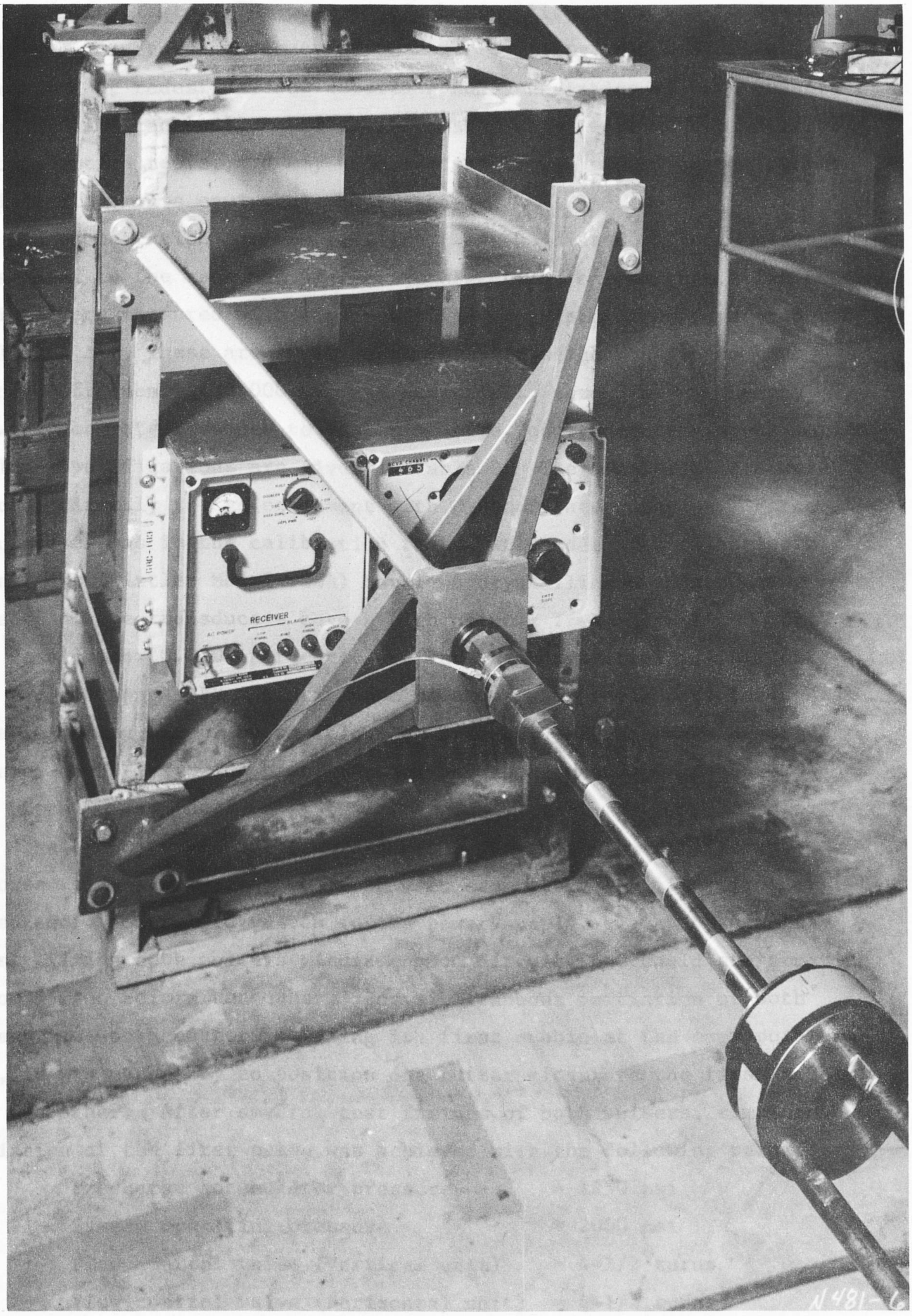


Figure 24. Biaxial test facility (closeup)

Facility Tests. The purpose of the facility tests was to demonstrate the structural adequacy of the test facility, allowing time for any repairs or redesigns, and ascertain characteristics of both pulsers operating simultaneously. During the tests, which were conducted after the calibration tests, a dummy weight of 75 lb was placed in the rack to simulate electronic equipment under test.

Instrumentation for the facility tests consisted of force measurements input to the rack and biaxial accelerations on the rack. The accelerations were measured with piezoresistive shock accelerometers (Endevco Model 2264 A). These are small gages (0.05-oz weight) having a high resonance frequency (30,000 Hz) and essentially zero damping thereby allowing accurate response to fast rise time, short duration shock motion. Complete specifications are given in Table 2. The accelerometers were attached directly to the equipment with cynoacrylate adhesive. Force measurements, as in the calibration tests, were made with piezoelectric force links (Kistler Model 936A) having a crystalline quartz sensing element. These transducers have a high natural frequency (25,000 Hz), high resolution (0.0004 percent), and very high sensitivity. All data were recorded on an FM magnetic tape recorder and played back through a tuneable analog filter on oscillograph traces. The tape machines were operated at 30 ips, wide band, thereby having a frequency response from DC to 20 kHz (half-power point response).

The two circuits in the hydraulic power supply have different response times. Delays of up to 30 msec are within specifications of the solenoid controlled valves in the power supply. Thus, by simultaneously firing both pulsers with a common circuit, one could start moving up to 30 msec before the other. For simultaneous initiation of both pulses, i.e. both cutters striking its first nubbin at the same point in time, it was necessary to position one cutter closer to the first nubbin than the other. After several test firings of both pulsers, simultaneous initiation of the first pulse was achieved with the following parameters:

Precharge accumulator pressure	= 1250 psi
System operating pressure	= 2000 psi
Flow control value (Vertical unit)	= 4-1/2 turns
Flow control valve (Horizontal unit)	= 6-1/2 turns

Horizontal cutter initial run-up = 7.5 mm

Vertical cutter initial run-up = 5.1 mm

After repeated firing with the same parameters, initiation of pulses between the two units was controlled to within only 7 msec. Typical data records from biaxial tests, produced directly from the tape recorder with no additional filtering, are shown in Figures 25 and 26. As can be seen in Figure 26, significant accelerations were recorded on the rack (800 g both vertical and horizontal directions) with relatively moderate input forces (approximately 2000 lb). No significant problems were encountered while operating the system in the biaxial mode, other than maintaining alignment, which is a critical inherent characteristic of the system. Structural adequacy of the facility was also verified as no damage was detected.

IMPEDANCE MEASUREMENTS

To simulate a response using equivalent force pulse trains requires intimate knowledge of the mechanical transmission characteristics between the pulse train input and the required response simulation locations. To obtain such knowledge, impedance measurements were required for the biaxial test facility.

Two sets of impedance tests were run. The first set, as specified in the original test plan (Reference 7), was conducted using a hammer to produce a force impulse. Data from these tests were to be used in deriving a pulse train to simulate field test response records. The other set of impedance tests was conducted using vibration sine sweeps. Frequency response data of the radio equipment and rack were obtained from these vibration tests. All impedance tests were conducted with the rack hard mounted to the floor and reaction structure.

Hammer tests. The system configurations shown in Figures 27 and 28 were utilized for the hammer impedance tests. Force impulses, induced by a calibrated hammer having a force link attached to its head, excited the system and the resulting accelerations were measured in both horizontal and vertical directions. Figure 27 shows the arrangement for the vertical impedance test. Horizontal testing was likewise performed with the vertical pulser attached and the input being applied horizontally.

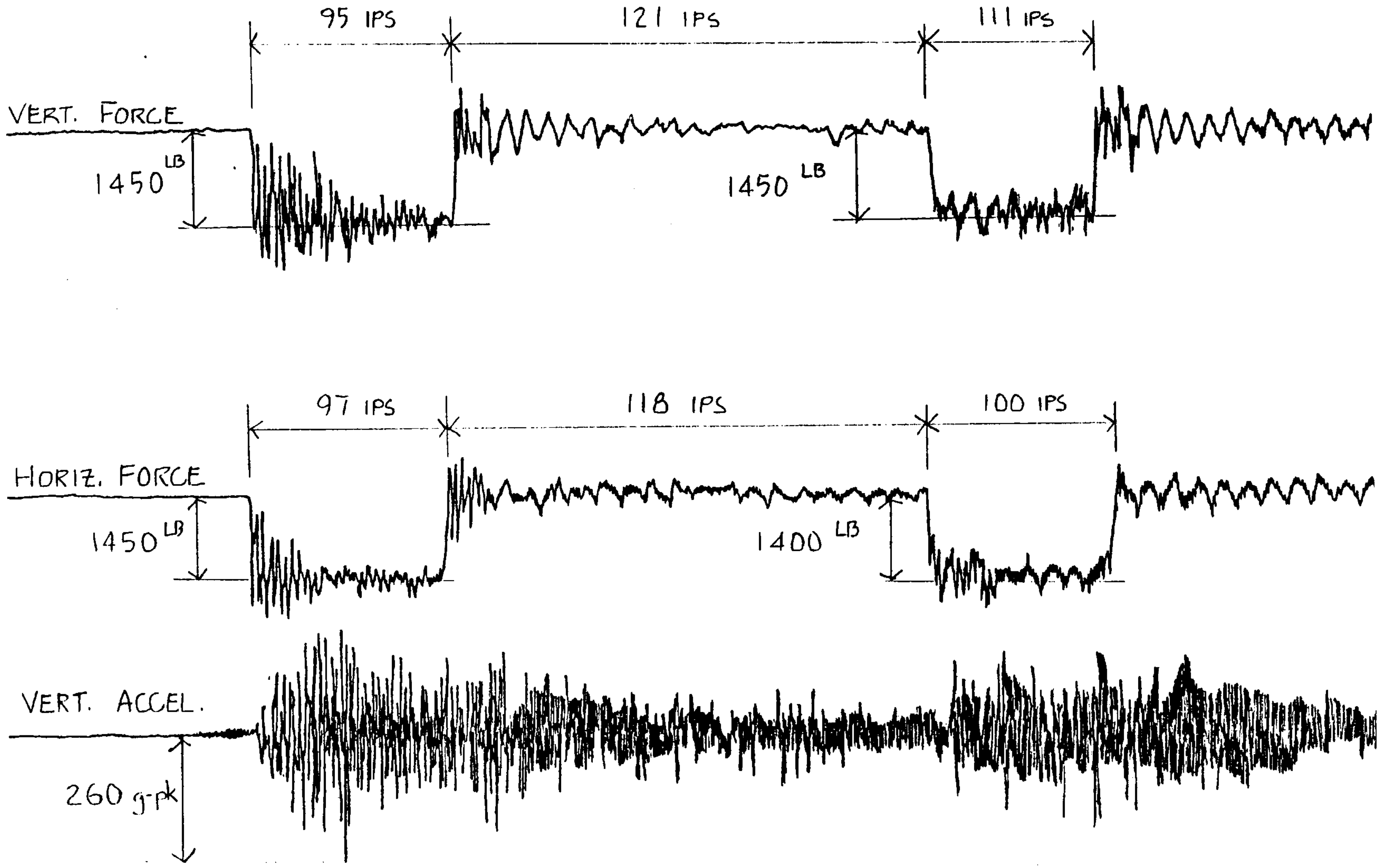


Figure 25. Biaxial pulse test data. Simultaneous pulse initiation

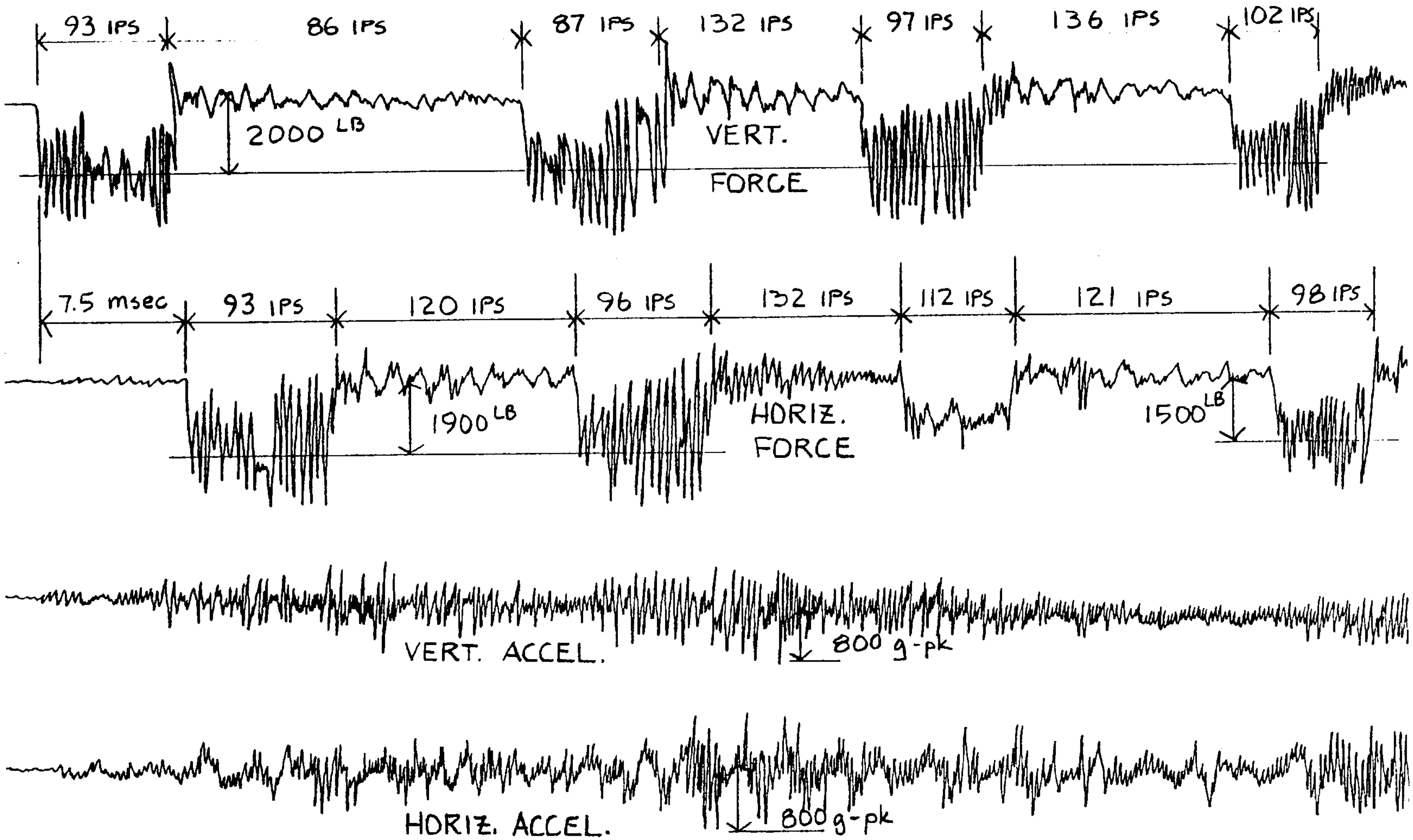


Figure 26. Biaxial pulse test data. Delayed pulse initiation

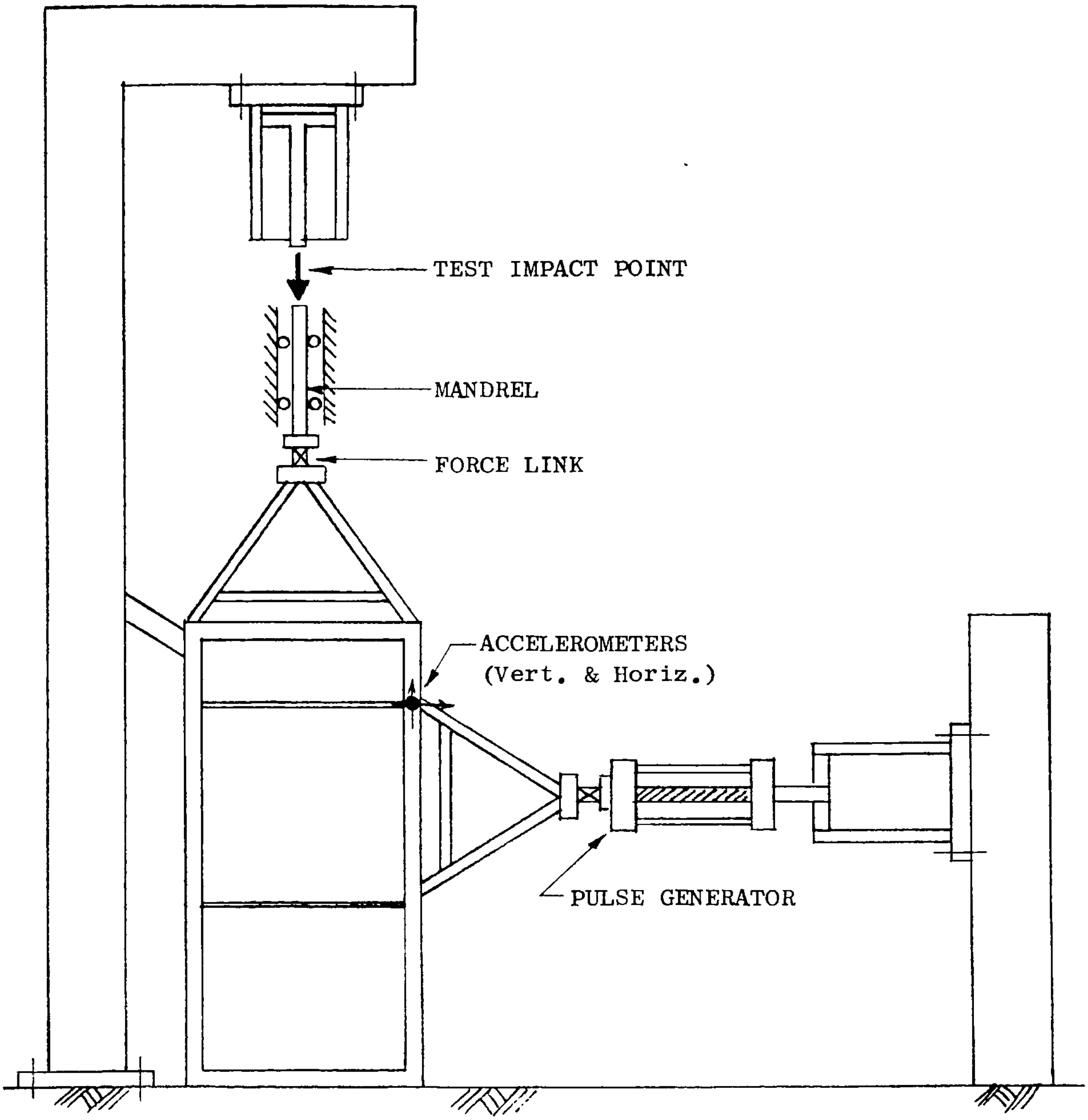


Figure 27. Vertical impedance test of biaxial test facility

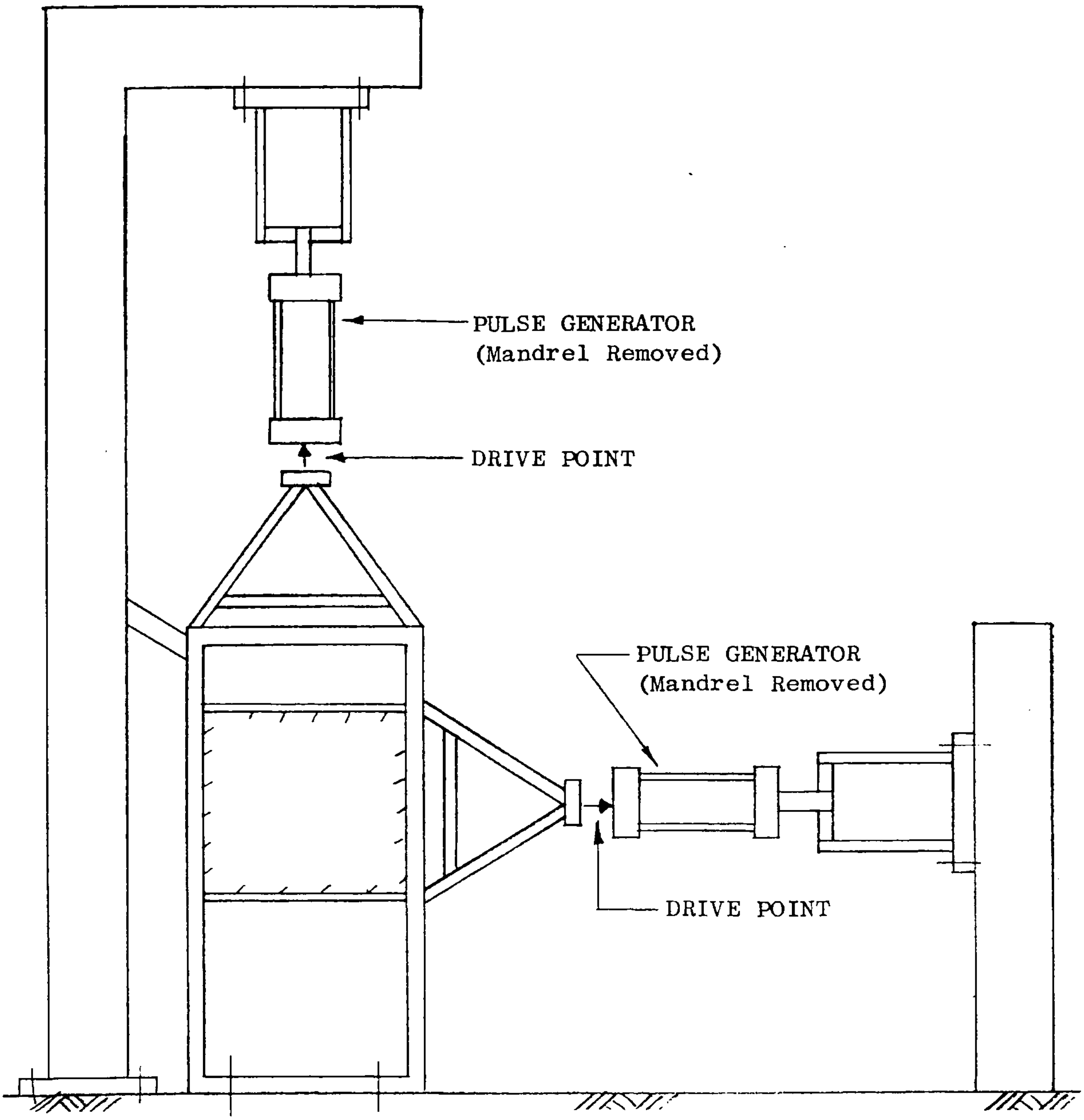


Figure 28. Source impedance measurement locations of biaxial test facility

Source impedance measurements were made, using the setup as shown in Figure 28, by exciting the pulse generators directly (pulse generators disconnected from equipment rack) and measuring the drive point acceleration. A nonoperational AN/GRC-103 radio system was mounted in the rack for all the impedance tests. The data were recorded on FM magnetic tape and later digitized. The digital records were forwarded to Agbabian Associates for analysis and use in the pulse optimization algorithms which are described in a later section of this report.

Vibration tests. Frequency response data of both the equipment rack and AN/GRC-103 radio were obtained from these tests. The pulsers were disconnected from the rack and an electromagnetic vibrator was attached to the horizontal loading yoke (Figure 29). Frequency sweep tests from 100 to 10,000 Hz were conducted using a 2-lb sinusoidal input. Other tests were conducted using 1-, 5-, and 20-lb input forces. Accelerations were measured at the point of loading, on a vertical leg of the rack, and on the face of the AN/GRC-103 transmitter.

Data from the vibration tests are shown in Figures 30-33. Figures 30-32, inertance functions, are ratios of acceleration frequency response to input force excitation. Inertance, sometimes called acceptance, is one of six descriptive transfer functions often referred to generically as impedance functions. Three impedance functions are ratios of response (displacement, velocity, or acceleration) to input force and three are the reciprocals. Most often used as the terms for these impedance functions are: compliance (or receptance), mobility (or admittance), inertance (or acceptance), dynamic (or apparent) stiffness, mechanical impedance, and dynamic (or apparent) mass (e.g. References 10,11). Figure 30 is the drive point inertance, Figure 31 is the inertance plot of the rack, and Figure 32 is the inertance plot of the radio as mounted in the rack. Comparing Figures 31 and 32 the general response characteristics of the rack and radio are quite similar. Several resonance peaks are observed in the 100- to 400-Hz range, with distinctive anti-resonances particularly prevalent in the 400-to 700-Hz range. Numerous resonances occur at frequencies above 1000 Hz, the strongest being at approximately 2600 Hz. Above 4000 Hz, the radio response has more anti-resonances than the rack. Figure 33 is a

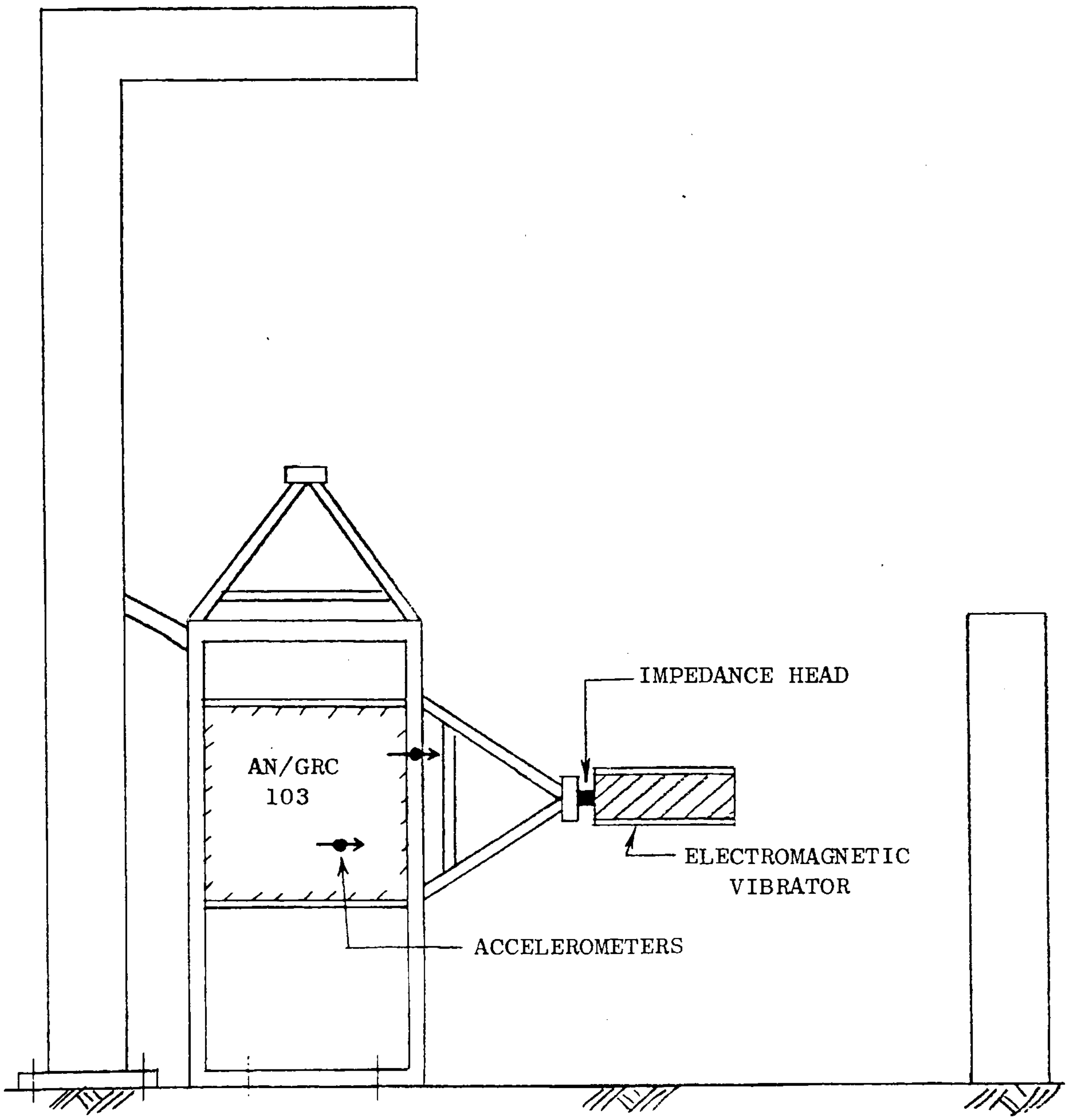
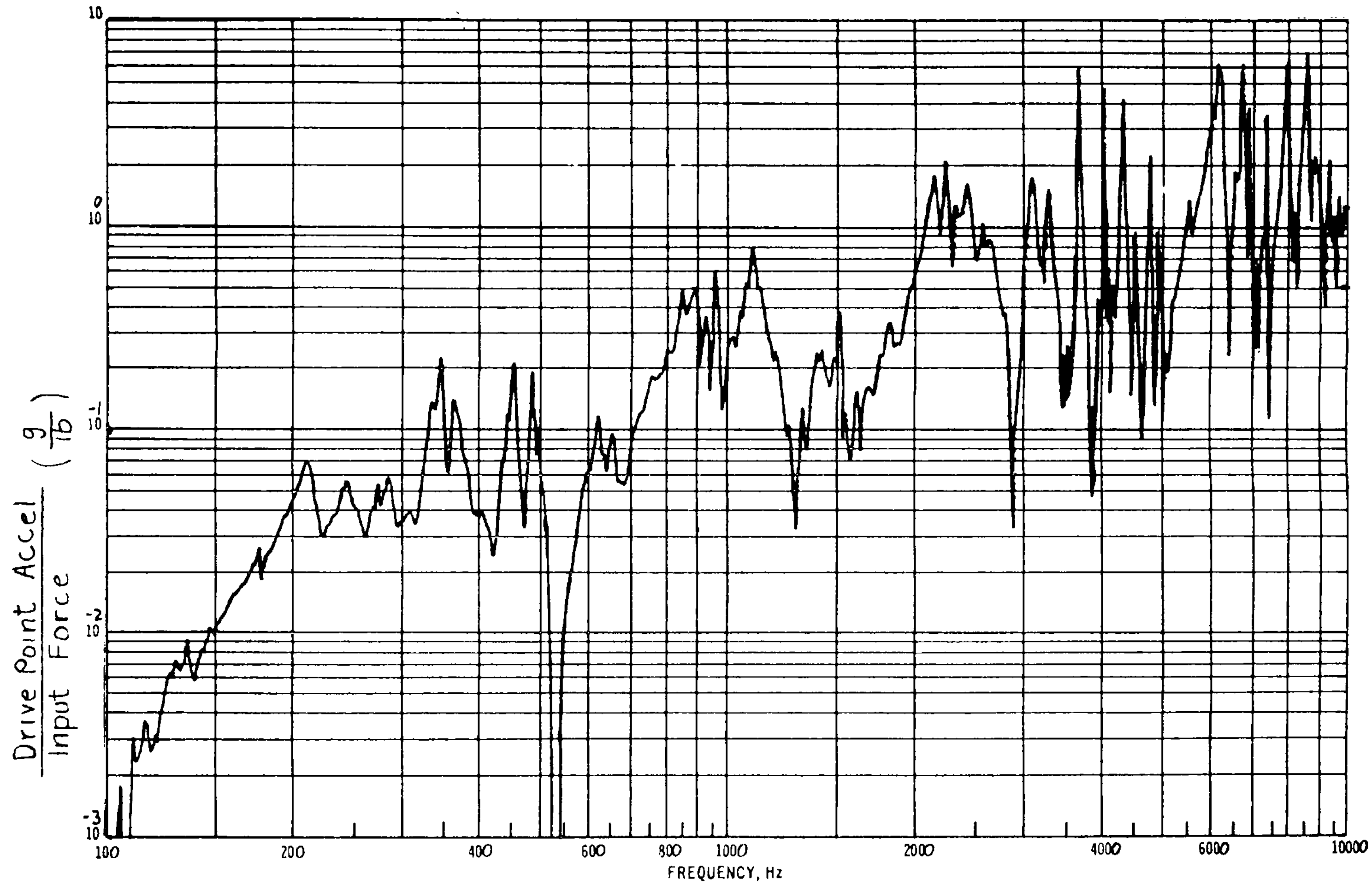
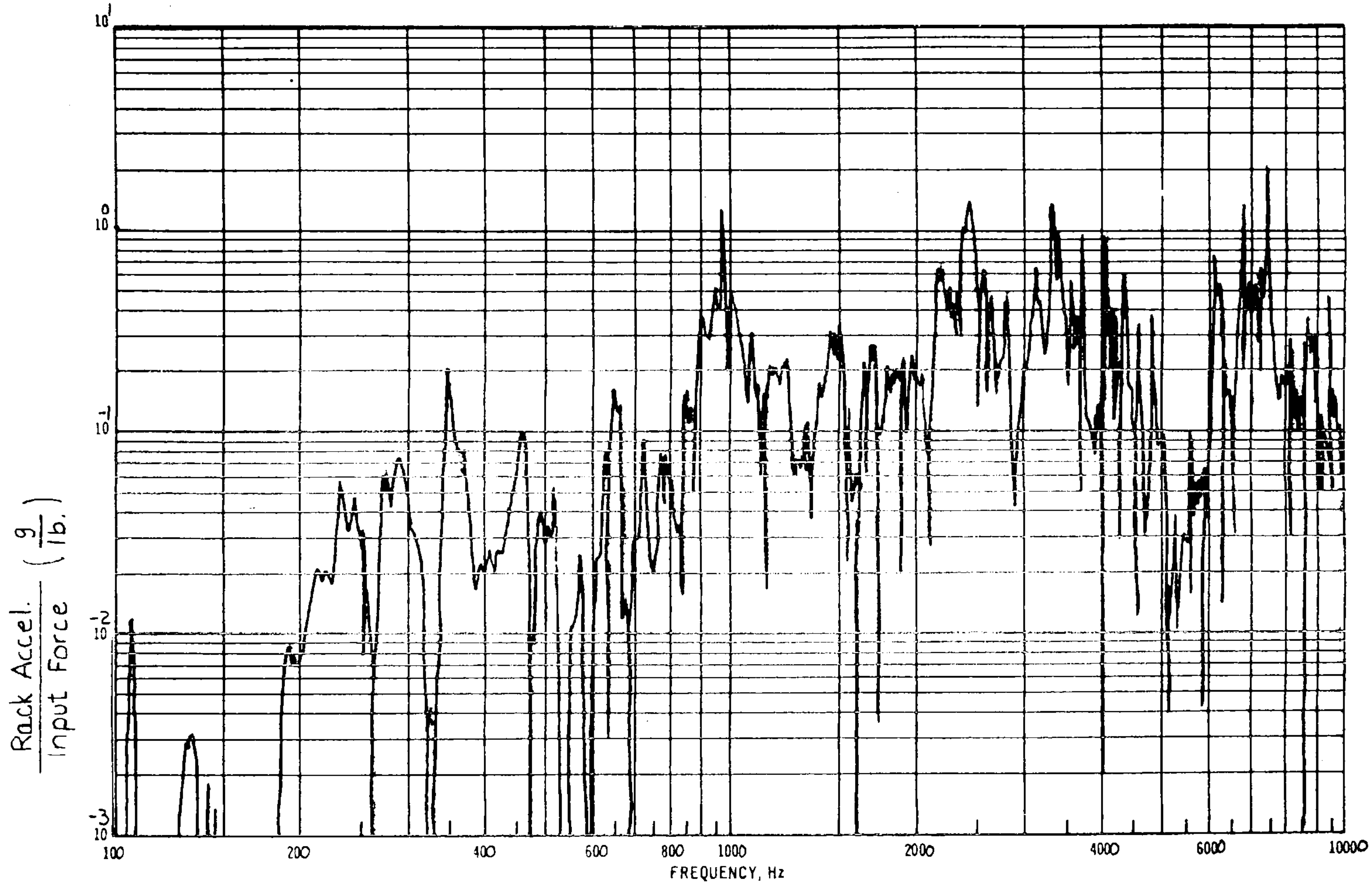


Figure 29. Vibration test setup



PROJ Pulser STRUCTURE Eqpt Rack OPERATOR Pickens TIME ____
TEST NO. ____ FREQ RANGE 100 - 10K HZ CAL FREQ ____ HZ HI CAL EQUIV 1.0 g / 2.0 lb DATE 10-2-80
EXCITER LOCATION Horiz Loading Yoke FORCE 2.0 LB FORCE CONTROL ____ YES ☑ NO ☐
PICKUP & LOCATION Drive Point Accel TYPE PLOT A/F PLAYBACK ☐ ON LINE ☑ MASS CANCEL ___ IN ☐ OUT ☐
ANALYZER FILTER BW 2.0 HZ SWEEP RATE 0.40 DECADE/MIN ____ HZ/SEC MODE MZ ☐ SPECTRUM ☐

Figure 30. Vibration test data. Drive point inertance



PROJ Pulser STRUCTURE Eqpt Rack OPERATOR Pickens TIME

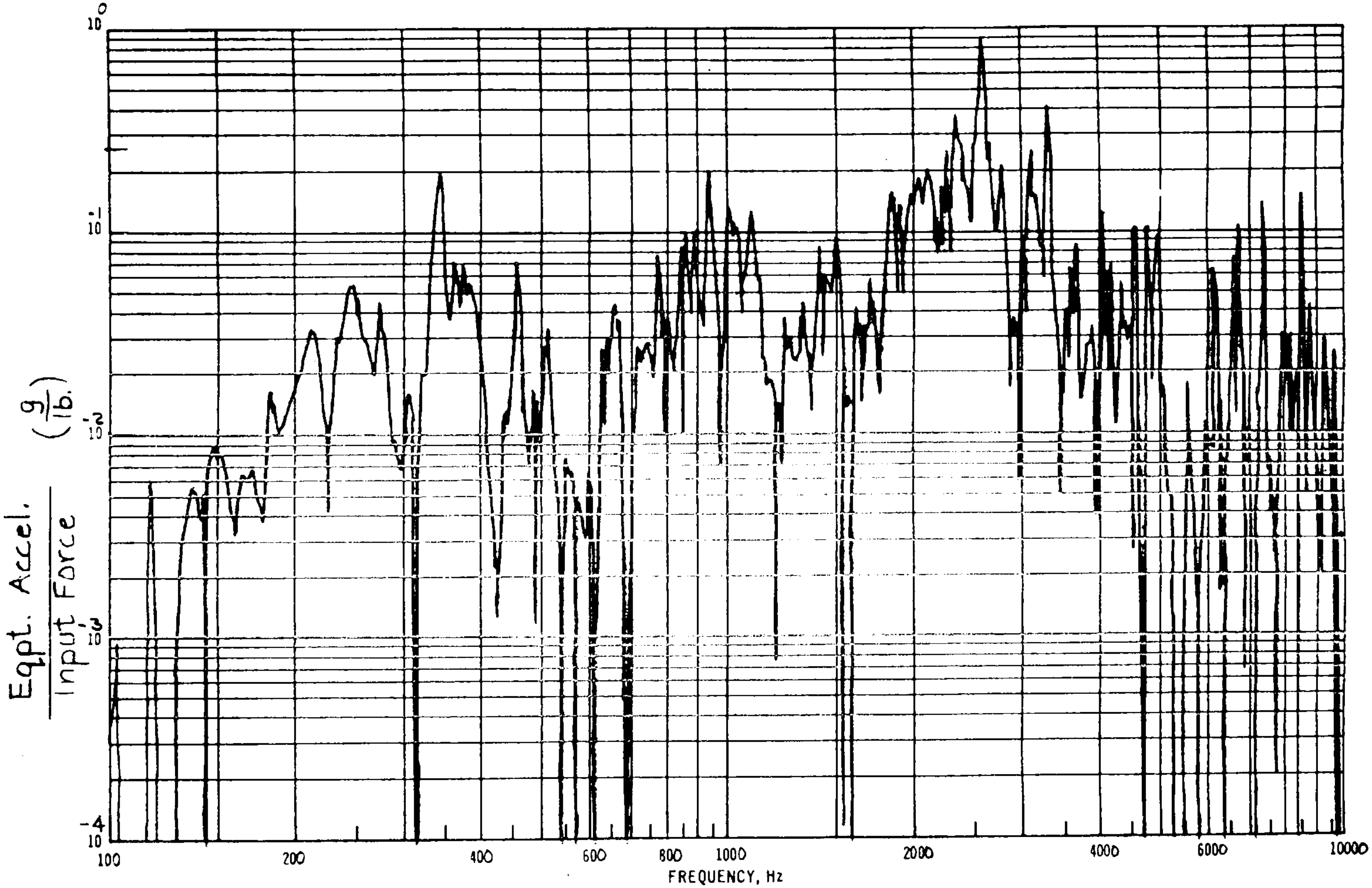
TEST NO. FREQ RANGE 100-10K HZ CAL FREQ HZ HI CAL EQUIV 2.0 g/2.0 lb DATE 10-2-80

EXCITER LOCATION Horiz. Loading Yoke FORCE 2.0 LB FORCE CONTROL YES ☑ NO ☐

PICKUP & LOCATION Eqpt Rack Vertical Leg TYPE PLOT A/F PLAYBACK ☐ ON LINE ☑ MASS CANCEL IN ☐ OUT ☑

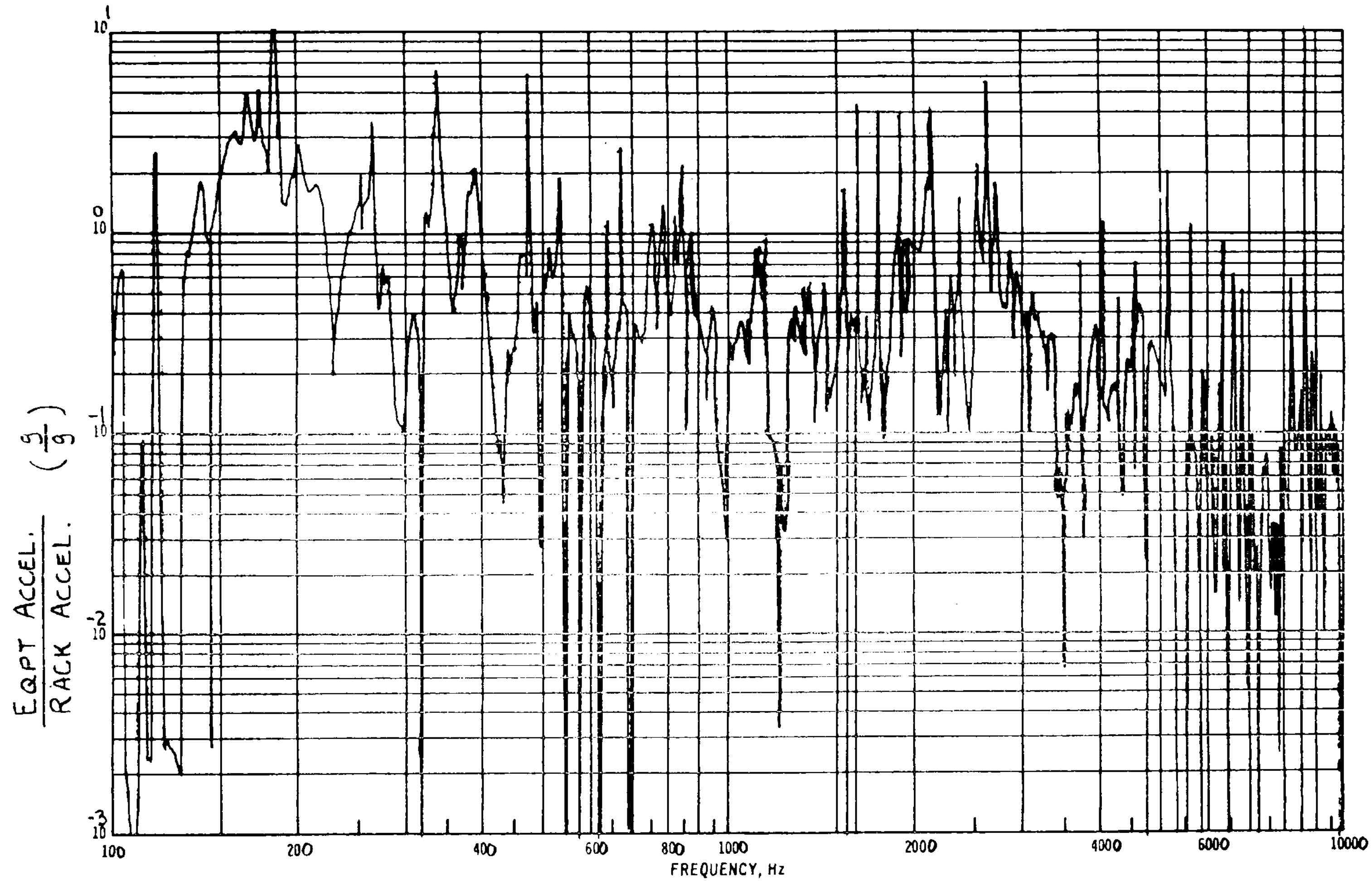
ANALYZER FILTER BW 2.0 HZ SWEEP RATE 0.25 DECADE/MIN HZ/SEC MODE MZ ☐ SPECTRUM ☑

Figure 31. Vibration test data. Equipment rack inertance



PROJ Pulser STRUCTURE Eqpt Rack OPERATOR Pickens TIME
TEST NO. FREQ RANGE 100-10k HZ CAL FREQ HZ HI CAL EQUIV 0.5g / 2.0 lb DATE 10-2-80
EXCITER LOCATION Horiz. Loading Yoke FORCE 2.0 LB FORCE CONTROL YES ☑ NO ☐
PICKUP & LOCATION Radio Eqpt Accel TYPE PLOT A/F PLAYBACK ☐ ON LINE ☑ MASS CANCEL IN ☐ OUT ☑
ANALYZER FILTER BW 2.0 HZ SWEEP RATE 0.25 DECADE/MIN HZ/SEC MODE MZ ☐ SPECTRUM ☑

Figure 32. Vibration test data. Equipment inertance



PROJ Pulser STRUCTURE Eqpt Rack OPERATOR Pickens TIME

TEST NO. FREQ RANGE 100-10K HZ CAL FREQ HZ HI CAL EQUIV 0.5g/2.0g DATE 10-2-80

EXCITER LOCATION Horiz. Loading Yoke FORCE 2.0 LB FORCE CONTROL YES ☑ NO ☐

PICKUP & LOCATION TYPE PLOT A/A PLAYBACK ☐ ON LINE ☑ MASS CANCEL IN ☐ OUT ☑

ANALYZER FILTER BW 2.0 HZ SWEEP RATE 0.25 DECADE/MIN HZ/SEC MODE MZ ☐ SPECTRUM ☑

Figure 33. Vibration test data. Transmissibility plot

transmissibility plot, the ratio of radio and rack accelerations versus frequency. As can be seen there are numerous lightly damped resonances and anti-resonances throughout the frequency range. There are distinctive peaks in the curve at frequencies below 400 Hz, particularly in the 150- to 200-Hz range, representing amplifications of up to 10 of radio versus rack accelerations. However, the curve generally falls in the 0.1 to 1.0 amplitude range signifying reduced accelerations being transmitted from the rack to the radio. This energy is apparently lost in the radio/rack bolted connection.

PULSE TRAIN DEVELOPMENT AND OPTIMAZATION

The basic premise on which the entire program is based involves simulating a measured or specified equipment acceleration response in the laboratory. To simulate the desired motion, specific pulse trains are required in order to excite the rack-equipment system such that the resulting motion will be that desired. Development of such pulse trains is the responsibility of AA. As originally planned this phase of the program would have already been completed. However, due to unexpected budget cuts experienced by the sponsor, funding for the project was stopped before the specific pulse trains were developed. The theory and methods to be used, taken primarily from References 7 and 8, are included for the sake of completeness.

The recorded data of acceleration-time histories from high explosive tests on the communications equipment are used as an objective function. This is the motion to be matched in both horizontal and vertical direction by the pulse tests on the equipment in a laboratory. The upper half of Figure 34 describes the field test and the lower half describes the computational procedure needed to generate the pulse train. In many situations high explosive field test data upon equipments are not available, in which case response motions from computer models may be used as the objective function. In this latter case airblast loads on scale models of the vehicle or shelter from shock tubes should be used with the finite element computer model of the structure.

Impedance measurements as described in the previous section were first made. These measurements, when converted to impulse functions, are

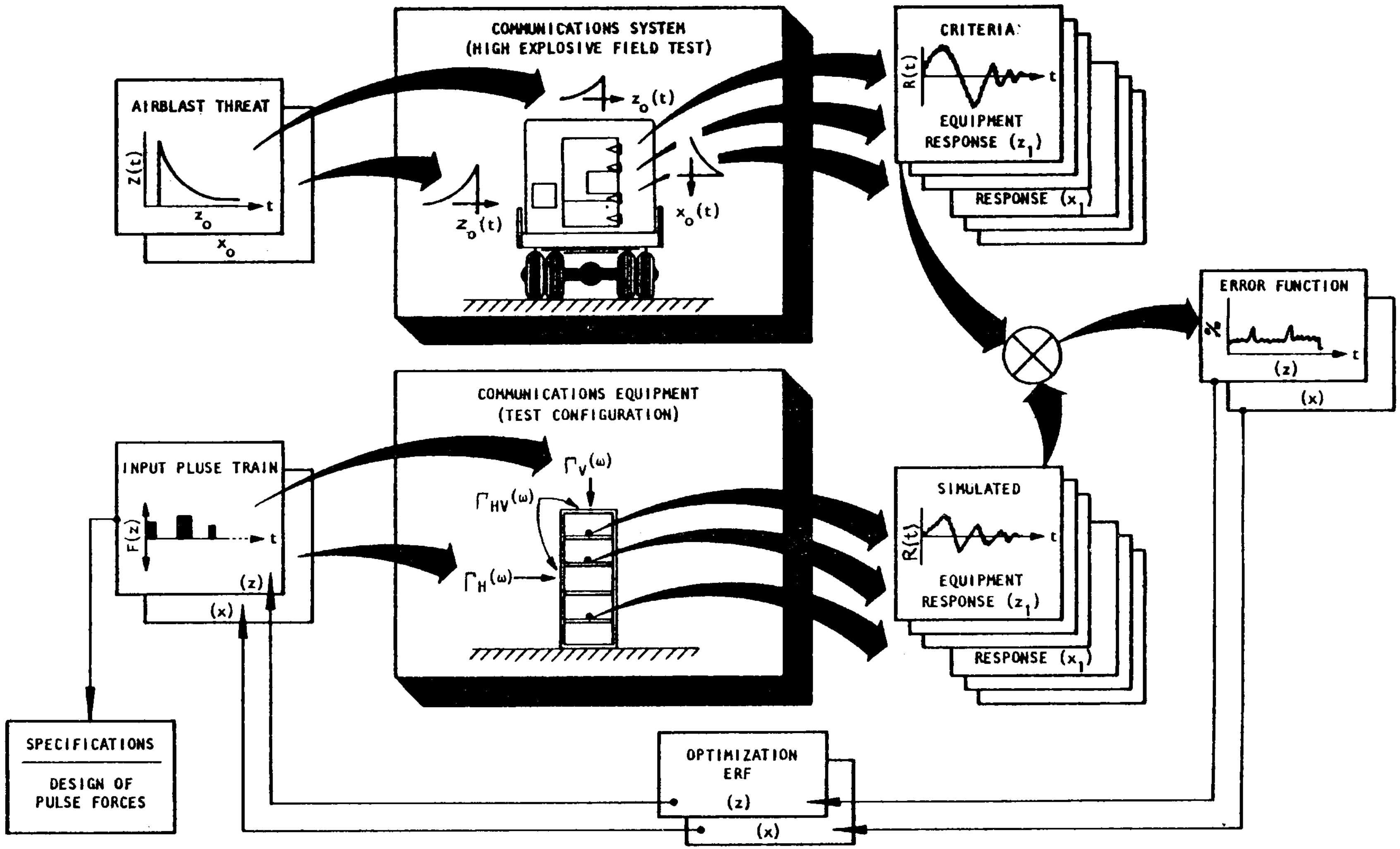


Figure 34. Optimum response of communications equipment by pulse excitation to match motions induced by air blast loads

used in the development of the pulse train, which is a series of rectangular pulses that vary in amplitude, time duration, and initiation time. An iterative optimization algorithm is used to tailor a pulse train to cause the test article to have response accelerations matching specified motions or motions experienced in the high explosive field tests.

Given a two-axes test, pulse trains are generated in accordance with the following matrix:

$$\underset{\text{Objective function}}{\begin{bmatrix} \ddot{X}_H \\ \ddot{X}_V \end{bmatrix}_{OF}} \longleftrightarrow \underset{\text{Pulsed motion}}{\begin{bmatrix} \ddot{X}_H \\ \ddot{X}_V \end{bmatrix}_P} + \underset{\text{System functions}}{\begin{bmatrix} \Gamma_H & \Gamma_{VH} \\ \Gamma_{HV} & \Gamma_V \end{bmatrix}} \underset{\text{Pulse trains}}{\begin{bmatrix} F_H \\ F_V \end{bmatrix}} \tag{3}$$

where

$\begin{bmatrix} \ddot{X}_H \\ \ddot{X}_V \end{bmatrix}_{OF}$ = Vertical and horizontal response acceleration motion from field tests (objective function)

$\begin{bmatrix} \ddot{X}_H \\ \ddot{X}_V \end{bmatrix}_P$ = Vertical and horizontal response acceleration motion due to pulse train inputs

Γ_H = Horizontal transfer inertance impulse function

Γ_V = Vertical transfer inertance impulse function

$\Gamma_{HV} = \Gamma_{VH}$ = Cross-axis transfer inertance impulse function (motions generated orthogonally to input axis)

$\Gamma = F^{-1}\left[\Gamma(j\omega)\right]$ = The impulse function, Γ , is the inverse Fourier transform of the complex ratio of output acceleration to input force over the frequency range of interest (inertance function)

$\begin{bmatrix} F_H \\ F_V \end{bmatrix}$ = Force pulse trains

Optimization iterations are continued until error functions, as given below for both vertical and horizontal motions of the equipment to be tested, are equal to or less than 5 percent.

$$\mathrm{erf} = \frac{\int_o^t (\ddot{X}_{OF} - \ddot{X}_p)^2 \, dt}{\int_o^t \ddot{X}^2_{OF} \, dt} \tag{4}$$

An adaptive random search method is used to determine the pulse trains for both the horizontal and vertical axes (Reference 9). These pulses are combined with the impulse functions, through the use of the convolution integral (Eq. 5), to induce motions in the equipment.

$$\ddot{X}_{\substack{\text{pulsed}\\ \text{motion}}} = \int_o^x F(t) \; \Gamma \; (x-t)dt \tag{5}$$

Since each individual pulse in the train is characterized by the independent parameters of amplitude, duration, and initiation time, a total of three parameters are needed to define each pulse and each direction. Thus, for example, if eight pulses are required for both vertical and horizontal direction, 48 parameters would be required.

The algorithm for the adaptive random search consists of alternating sequences of a global random search with a fixed value for the step size variance (σ) followed by searches for the locally optimal σ . Figure 35 illustrates the adaptive algorithm whereby a very wide-range search selects the best standard deviation of step size for the coarseness of the increments used, followed by a sequential search of finer

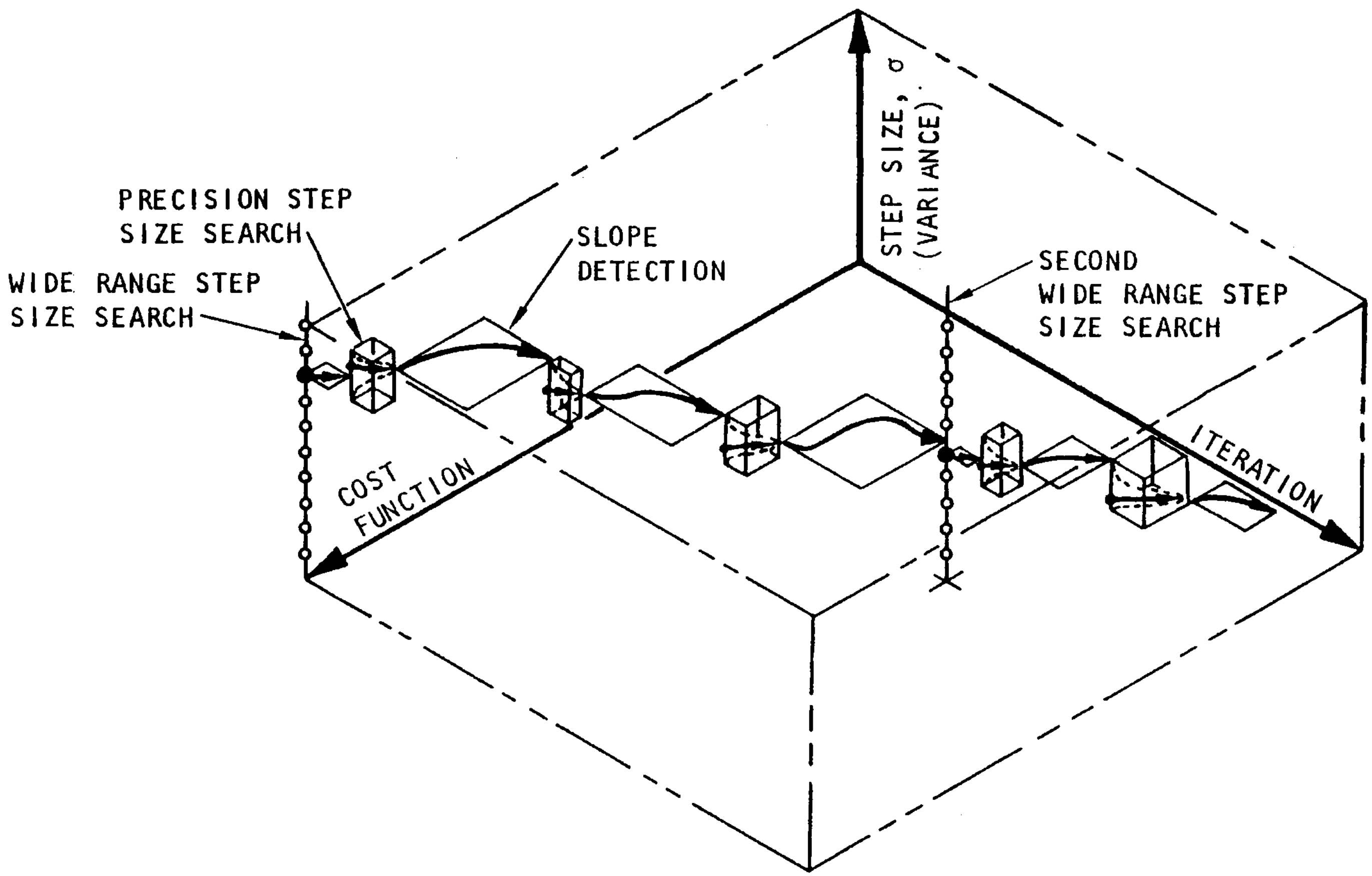


Figure 35. Adaptive step size search, both wide range and precision, for rapid convergence of cost function

increments. As the rate of convergence decreases, a new precision search is made, but directed towards a smaller step size. At selected iteration intervals, the wide-range search is reintroduced to prevent convergence to local minima.

SIMULATION TESTS

As originally planned, simulation tests on various classes and pieces of equipment comprising the communication system would be conducted using specified pulse trains obtained in the pulse train development phase. However, since the pulse train development has been postponed due to budget cuts, the original test plan was modified. The sponsors, BRL and ERADCOM, wanted whatever data that could be obtained from tests of actual pieces of equipment, within funding limitations. Since a substantial quantity of unused aluminum nubbins remained from the calibration phase, tests could be conducted on available equipment using generic pulse trains. Even though the resulting motion would not exactly match the field test records, it was anticipated that they would be similar in nature. Furthermore, available field test records represented motions of the rack rather than the actual equipment, because of failure of equipment mounted accelerometers during the field test. Of significance was some insight to the question of how much of the rack motion was transmitted to the equipment. Information relating to this area could be highly beneficial in determining the best placement of equipments in a high explosive event scheduled for fall 1981. Thus, using available funds and nubbins, tests were conducted on two pieces of communication equipment, the AN/GRC-103 transmitter-receiver, and the TD660 multiplexer. Since generic pulse trains were used, horizontal, single axis excitation was deemed sufficient.

<u>Tests of Operational Equipment</u>. Two units of operation equipment were delivered to WES for testing; (a) AN/GRC-103 Transmitter and Receiver, and (b) TD660 Multiplexer. These units were brought to WES, installed in the rack, and operated on line during testing by personnel from the U. S. Army Depot, Tobyhenna, Pennsylvania. Horizontal, uniaxial pulse tests were conducted on these units utilizing the same instrumentation as in the impedance tests, i.e., accelerometers on the rack vertical

leg and on the face of the equipment along with the force link. Initial tests were run with the AN/GRC-103 installed, but not on line, followed by on-line tests of both the AN/GRC-103 and TD660.

Both transmitter and receiver were mounted in the rack using standard mounting angles and screws. Six tests were conducted utilizing different pulse trains (Figure 36) in the horizontal axis. The tests are summarized in Table 4 and typical data are presented in Figures 37-40. The data were digitized at rates of 20,000 and 10,000 samples per second, thereby limiting the useful frequency ranges to 10 and 5 kHz, respectively (based on conventional digitizing procedures). Data for each test were analyzed in the form of time histories, fast Fourier transforms (FFT's), auto correlations, cross correlations, and cross spectral density records. For the data in the frequency domain (at the 10K digitizing rate, both fine and coarse plots were made, i.e., the curves were defined with either 1024 points or 512 points. The coarse data plots, gross approximations of the actual curves, are often better for visualization of the data.

There was no apparent damage to any of the pieces of equipment during the tests. The off-line tests of equipment were conducted using nonoperational units followed by the tests of operational units. For the operational, on-line tests, the units were turned on several minutes before testing and allowed to operate several minutes after testing. Even though relatively high acceleration levels were measured on the rack (up to 2000-g peak) the equipment suffered no apparent damage. This leads to a closer look at what the measured accelerations actually indicate.

The motions measured on the rack and that transmitted to the equipment are highly dependent on the particular pulse train. Maximum utilization of the pulse generator, leading to maximum loading of the equipment can only be accomplished using specifically designed pulse trains taking into account the dynamic characteristics of the total system being tested. The energy accepted by the equipment is frequency sensitive, and the frequency content of a particular pulse train cannot be predetermined without a detailed analysis. However, the general pulse trains used in these initial tests were quite useful in determining how the equipment responds to motions input to the rack.

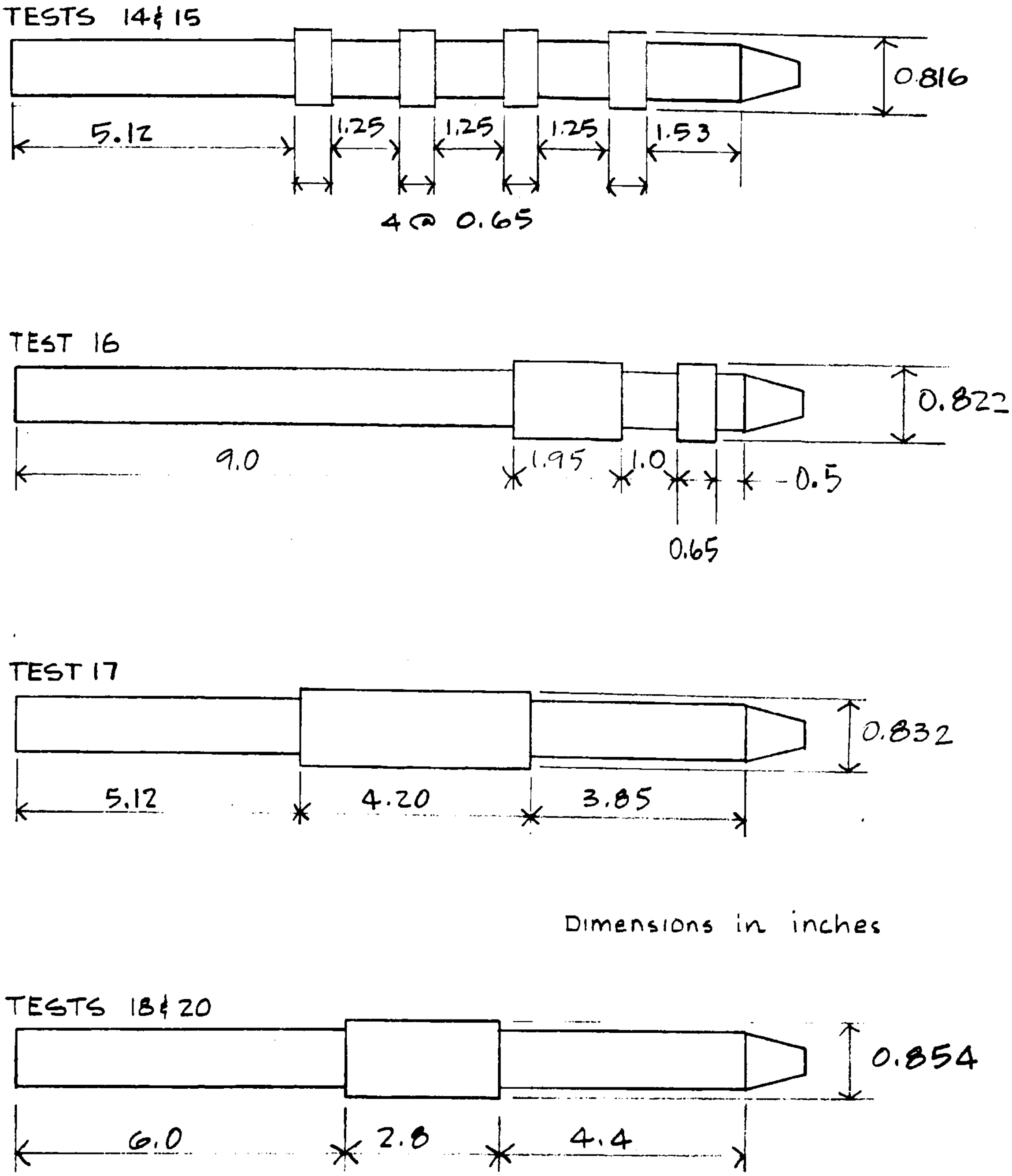
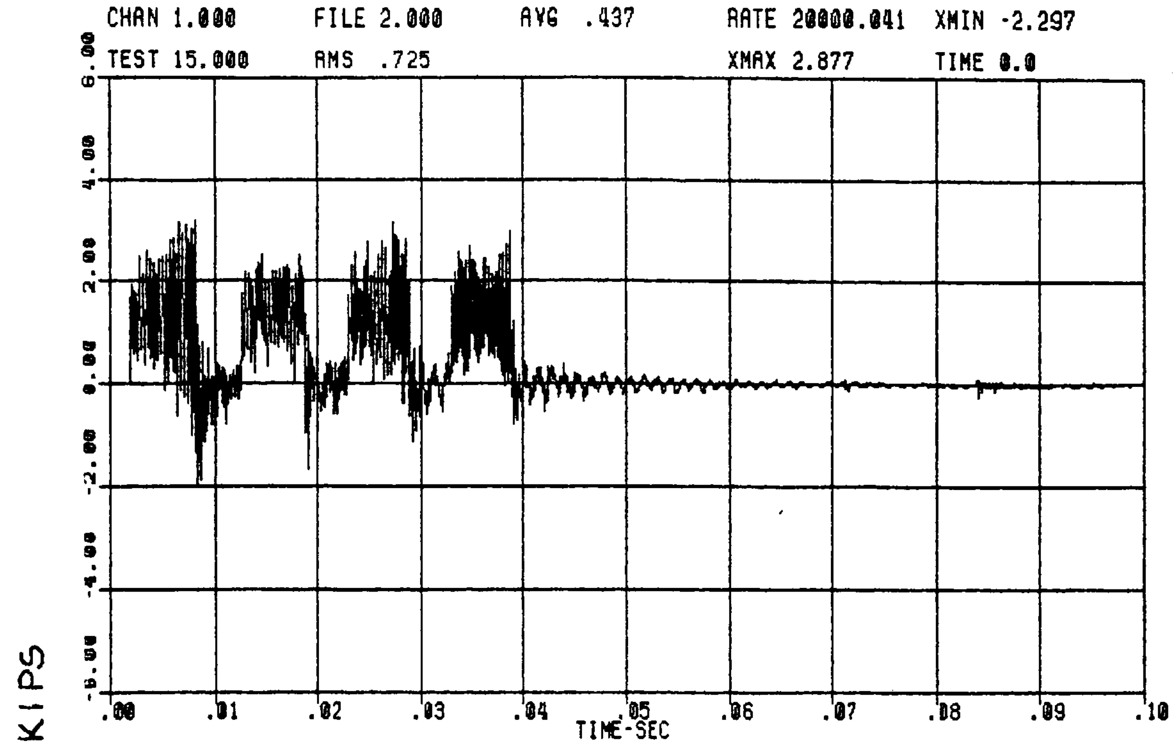


Figure 36. Pulse trains for tests 14-20. Rack "hard mounted"

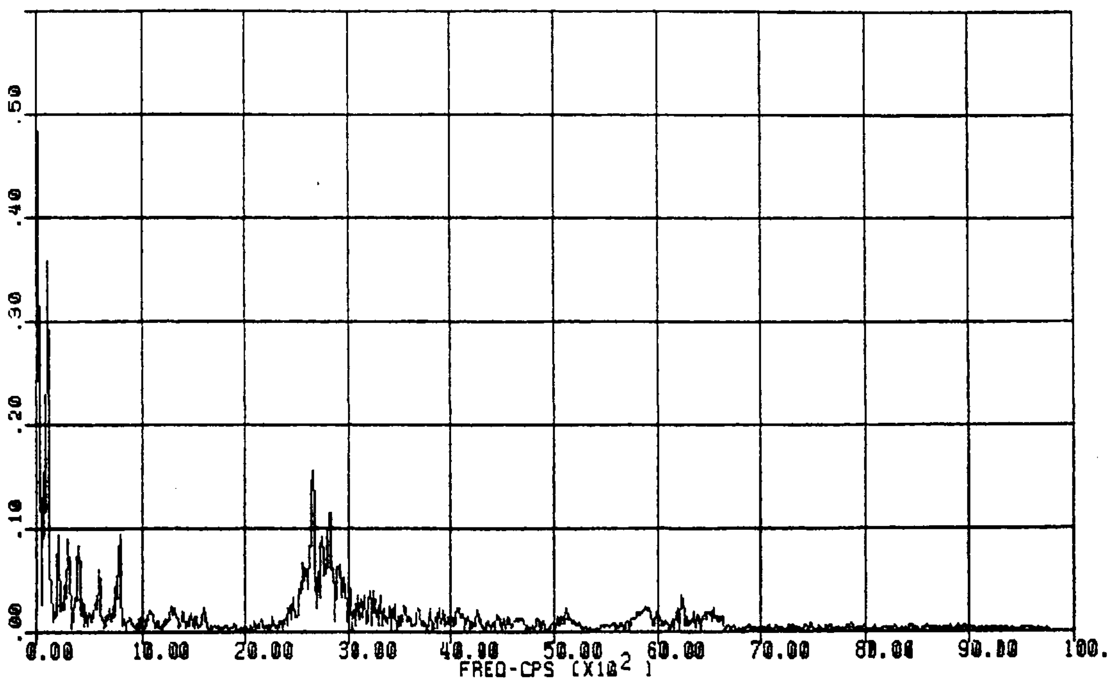
Table 4

Summary of Tests 14-20, Rack Hard Mounted

Test No.	Average Force (lb)	Rack Acceleration (G)			Equipment Acceleration (G)			$\left[\frac{EQPT}{RACK}\right]$ RMS	Low-Pass Filter (kHz)	Notes
		MAX	RMS	$\frac{RMS}{MAX}$	MAX	RMS	$\frac{RMS}{MAX}$			
14	1100	516	111	0.23	88	20	0.23	0.18	10	AN/GRC 103, off-line
	1000	116	38	0.24	69	18	0.26	0.47	5	
15	1400	428	68	0.16	165	26	0.16	0.38	10	" "
	1400	232	38	0.16	109	20	0.18	0.52	5	
16	1500	477	81	0.17	130	24	0.18	0.30	10	" "
	1400	175	28	0.16	86	15	0.17	0.54	5	
17	2400	968	176	0.18	208	48	0.23	0.27	10	" "
	2200	202	47	0.23	152	42	0.28	0.89	5	
18	4000	2029	257	0.13	167	32	0.19	0.12	10	AN/GRC 103, on-line
	4000	772	114	0.15	85	22	0.26	0.19	5	
20	4000	1750	302	0.17	148	30	0.20	0.10	10	TD660, on-line
	4000	800	194	0.24	88	22	0.25	0.12	5	



(a) Input Force Time History



(b) Input Force FFT

Figure 37. Input force data - Test 15

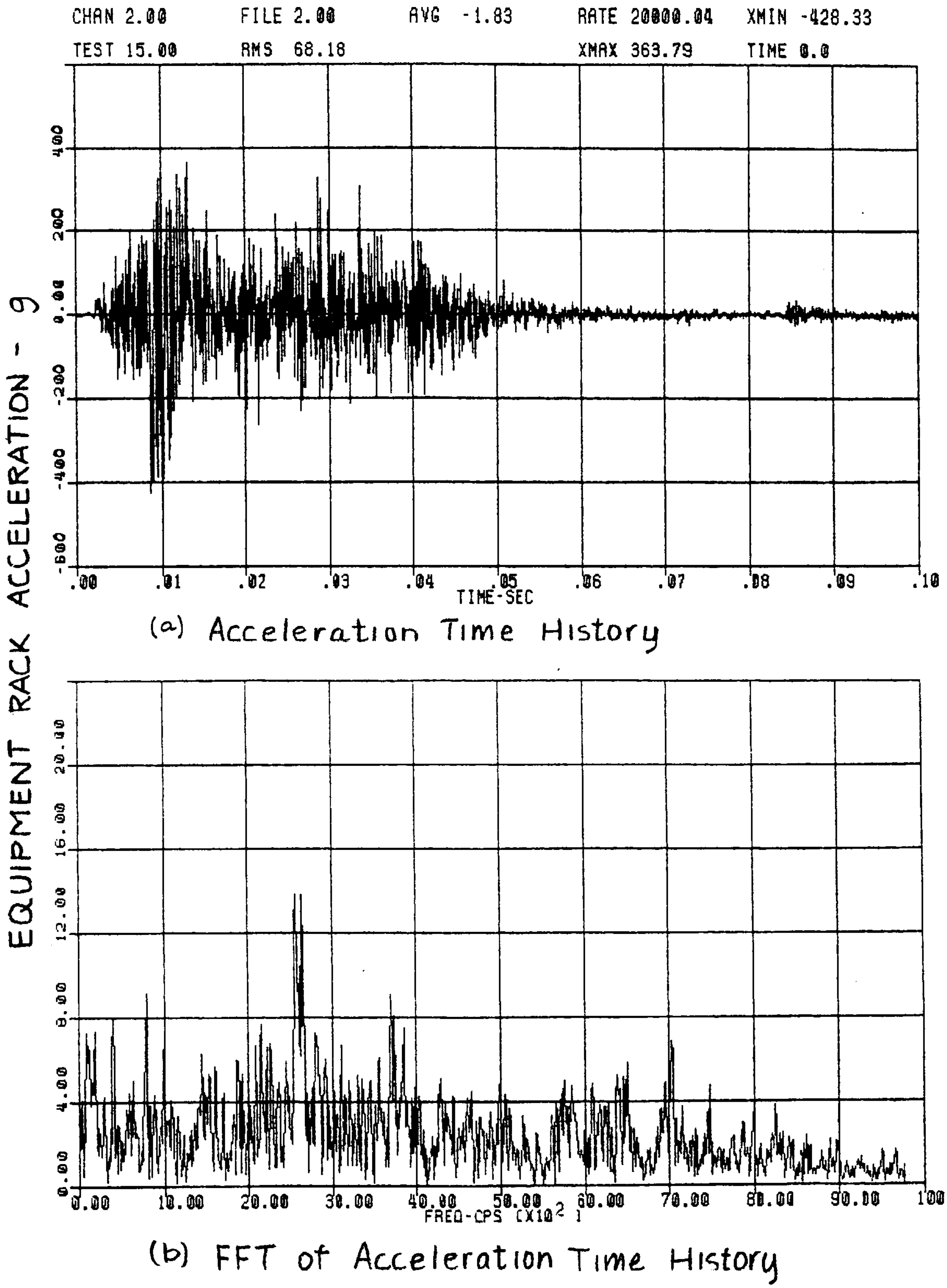
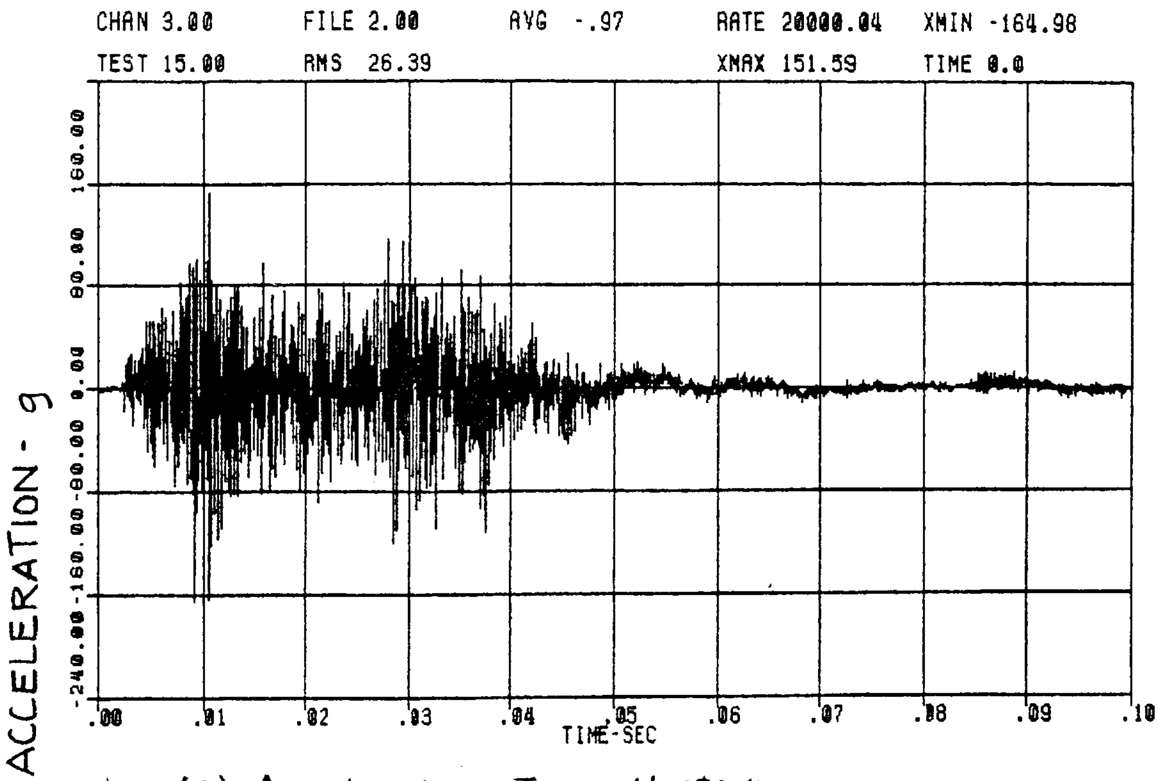
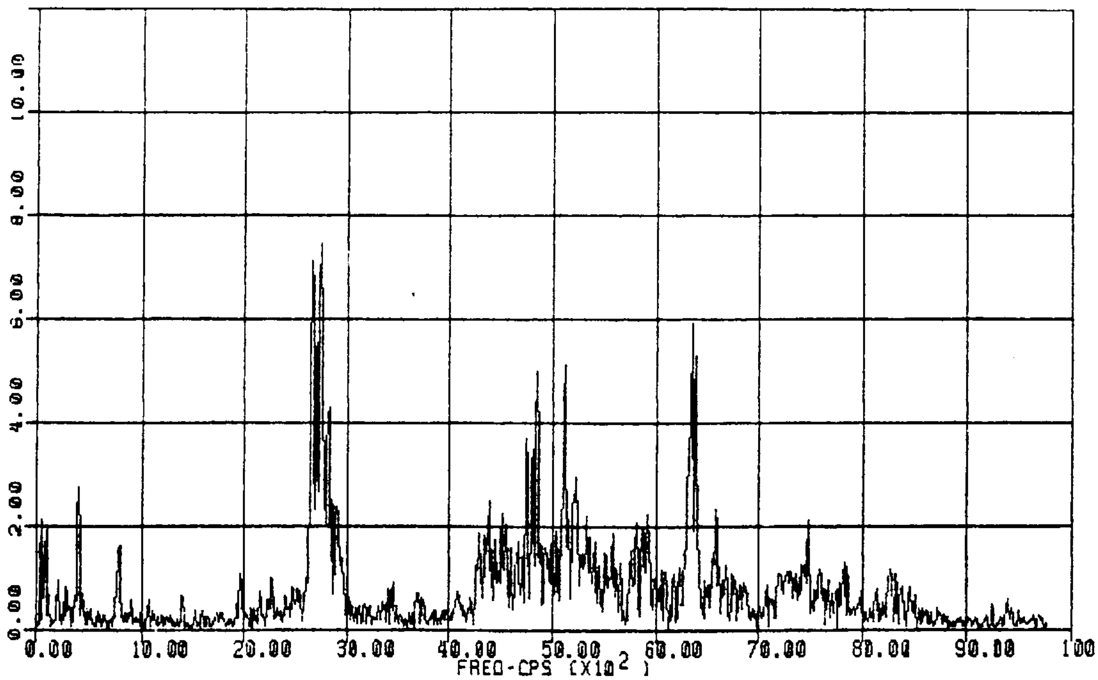


Figure 38. Equipment rack response data - Test 15

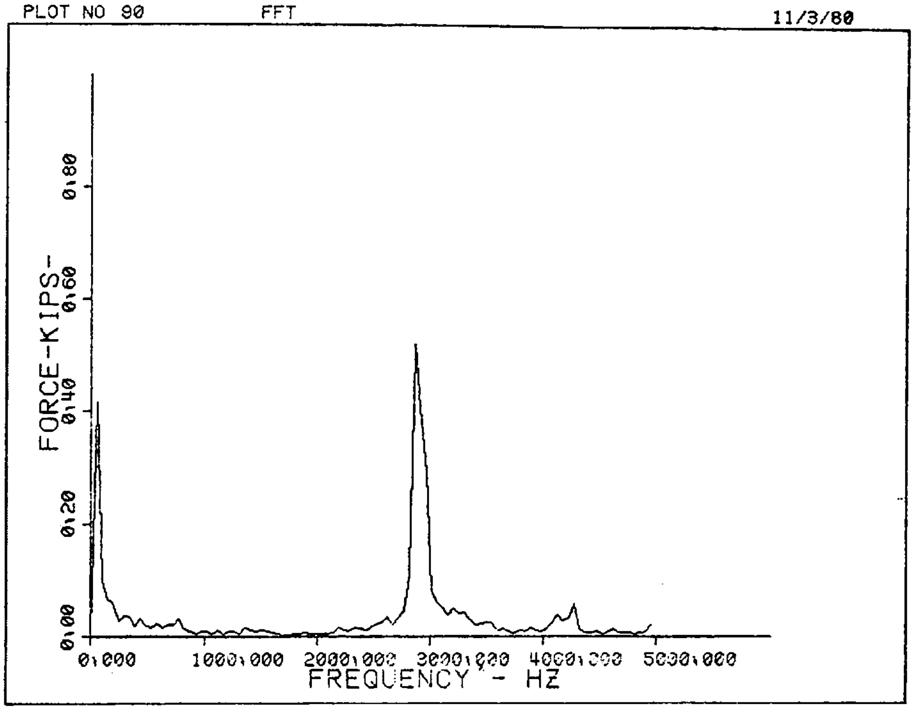


(a) Acceleration Time History

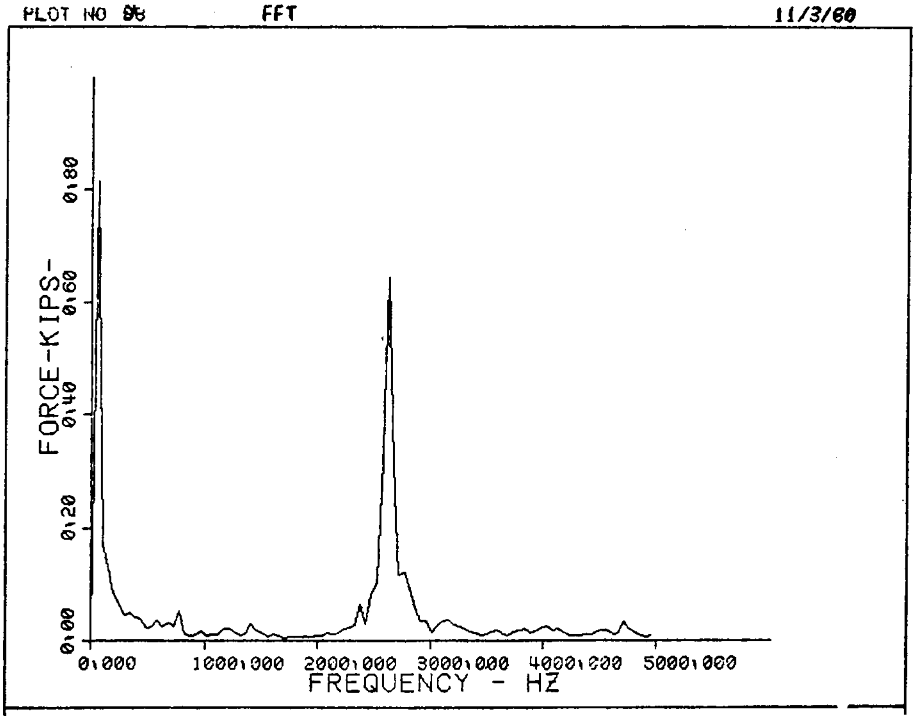


(b) FFT of Acceleration Time History

Figure 39. Equipment response data - Test 15



(a) TEST 17 Input Force FFT



(b) TEST 20 Input Force FFT

Figure 40. Input force frequency content, data limited to 5000 Hz, Tests 17 and 20

The accelerations measured on both the rack and the equipment contain sharp, high-frequency peaks. The 10-kHz filtered data contain rack acceleration peaks of up to 4.8 times those of the 5-kHz limited digitized records (Test 17, Table 4). For Test 15 the 10-kHz rack peak accelerations were only 1.8 times those of the 5 kHz records. However, the pulse trains of Tests 15 and 17 were significantly different. Perhaps more important than peak response is the RMS value of measured acceleration. The 5-kHz RMS acceleration response of the equipment in Test 17 was nearly equivalent to that of the rack (42 g versus 47 g). Thus, for this pulse train the transmissibility of energy from rack to equipment was quite high (89 percent). However, in Test 20, the RMS equipment response was only 22 g compared to rack RMS response of 194 g, giving a transmissibility of only 12 percent. The ratios of equipment RMS response to rack RMS response are shown in Table 4 for each test. It is of interest to note that although the pulse trains of Tests 20 and 17 are quite similar (except for depth of cut, i.e., nubbin diameter), these two tests represent the extremes of equipment to rack response ratios (0.89 for Test 17 and 0.12 for Test 20).

Upon comparing the FFT's for the force input for each test, Figure 40, it is seen that the primary frequency content is 2880 Hz for Test 17 and 2620 Hz for Test 20. This relatively small difference in frequency content of input force can significantly change the transmissibility ratio of equipment to rack response. This is quite apparent when considering the transmissibility plot of Figure 33 from the vibration tests. Extremely large differences in the ratio, on the order of 1000 to 1, exist for only minute changes in frequency. This is simply the nature of the rack-equipment system. It is a lightly damped, ringing type of structure having numerous resonances. It must also be kept in mind that the vibration tests were conducted using a 2-lb force input, and the resonances and anti-resonances for both rack and radio could change significantly for a force input of several thousand pounds due to nonlinearity in the system.

Cutter chatter. Consider the force input FFT for Tests 14-20 (Figures 37(b) and 41). With the exception of Tests 14 and 15 there is a predominant peak occurring in the 2500-to 3000-Hz region, indicating that most of the input force is at this frequency. This harmonic motion is

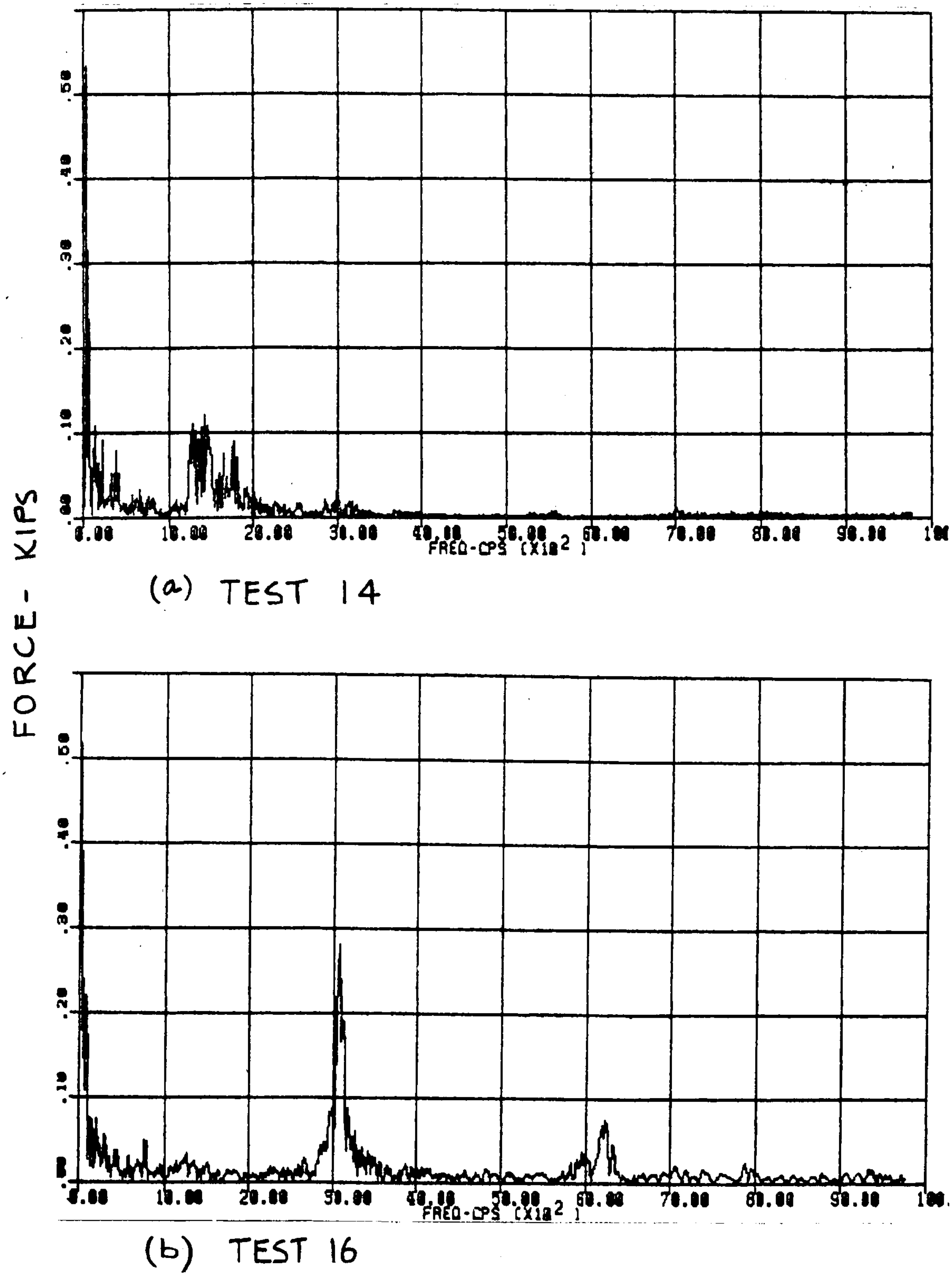
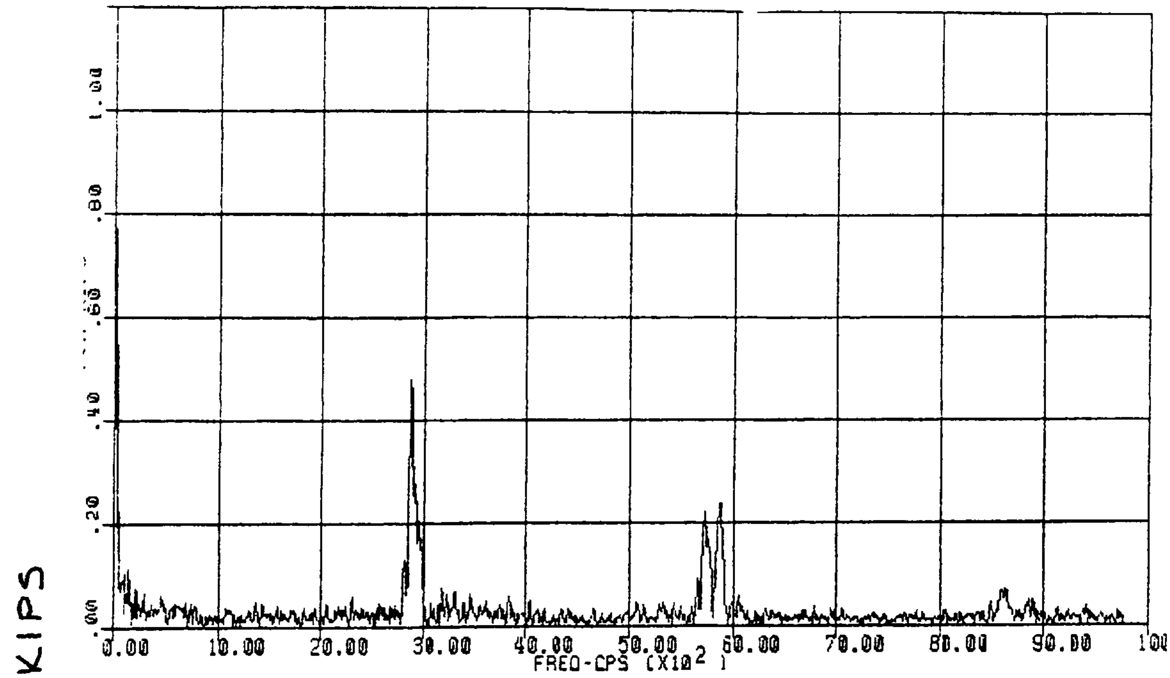
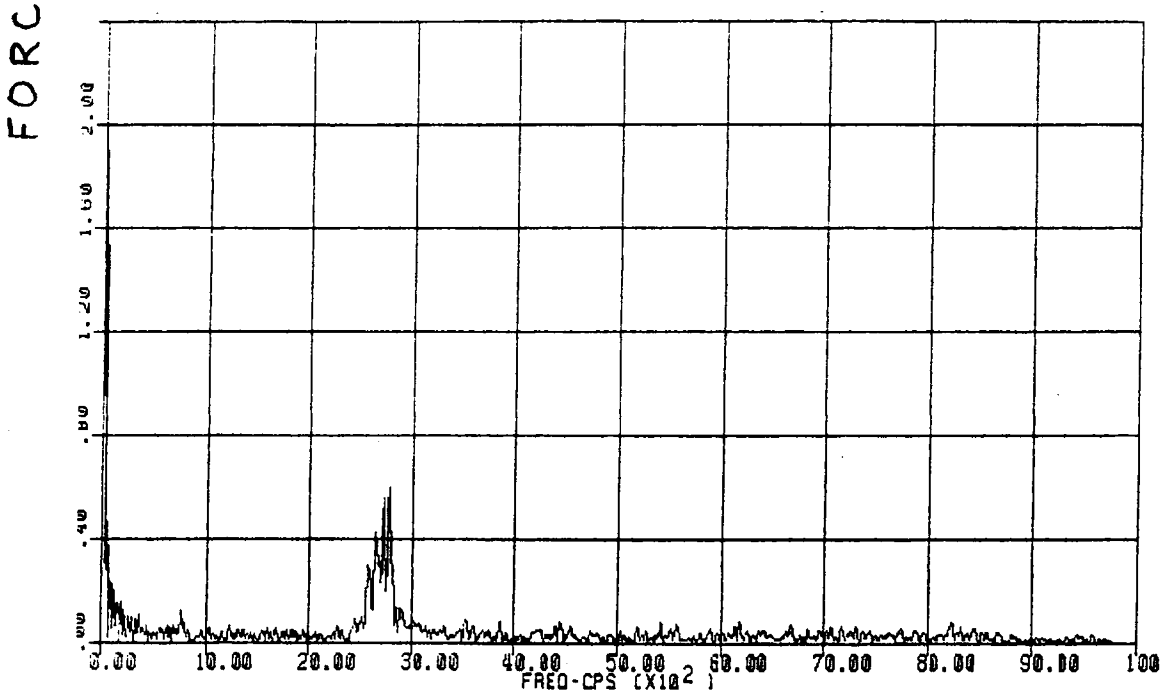


Figure 41 (Sheet 1 of 3). Input force frequency data, Tests 14-20

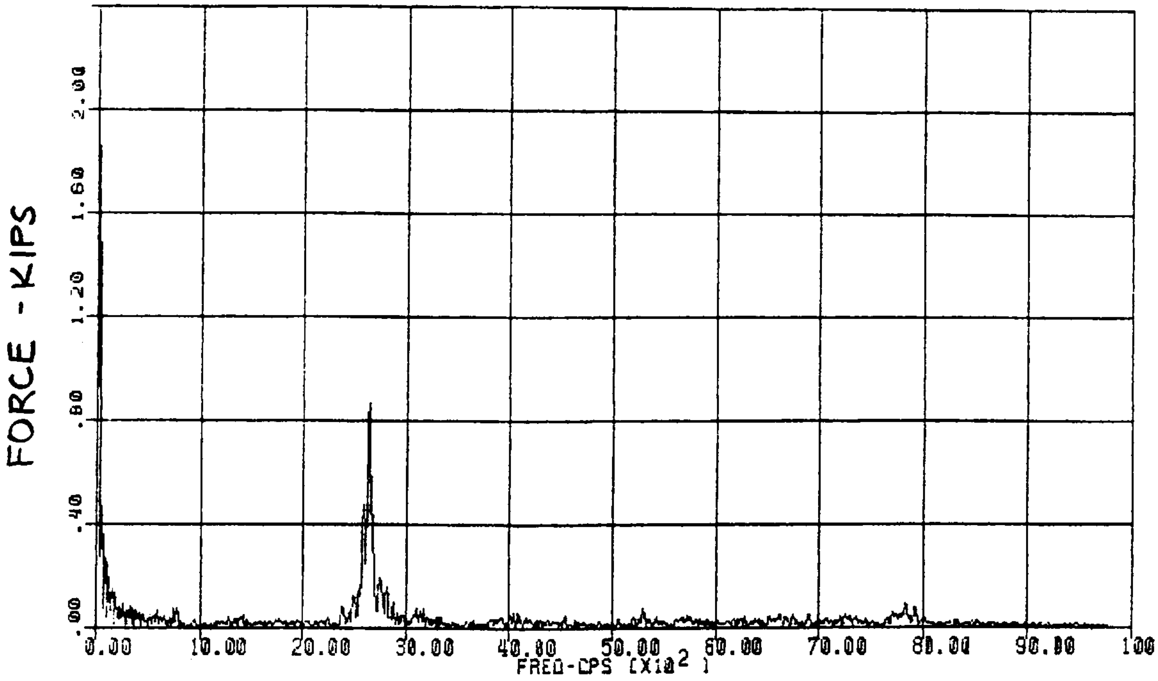


(c) TEST 17



(d) TEST 18

Figure 41 (Sheet 2 of 3). Input force frequency data, Tests 14-20



(e) TEST 20

Figure 41 (Sheet 3 of 3). Input force frequency data, Tests 14-20

also seen on the auto correlation functions of the force inputs. This motion is due to chatter in the pulse generator as the cutter plows through a nubbin. The chatter is also apparent in the cut nubbin as the cut surface contains ripples rather than being smooth. The deeper and longer the cut the greater the amount of chatter.

During the calibration tests a different cutter geometry was tried in an effort to reduce this chatter. However, the new cutter, which utilized a rake angle, did not reduce chatter; it actually increased it somewhat. The pulse train used in Tests 14 and 15 contain several short nubbins, as opposed to a single longer nubbin, and the chatter is not as severe. This fact is reflected in the FFT's of the input force for these tests, which do not exhibit the large spike in the 2500- to 3000-Hz region.

TESTS OF "SOFT MOUNTED" EQUIPMENT RACK

In an effort to introduce higher accelerations into the equipment, at lower frequencies, the equipment rack mounting configuration was changed. For all previous tests the rack was secured directly to the concrete floor with four anchor bolts and tied to the reaction structure with a steel angle and bolts. This type mounting arrangement was considered to be a "hard mount." The "soft mount" arrangement, shown schematically in Figure 42, consisted of using Firestone Airmount Isolators (air bags) for all horizontal support. The floor anchor bolts were removed as was the horizontal steel angle positioned at the top of the rack. The rack was attached to four air bags (two at the top and two at the bottom) as shown in Figures 43-45. The air bags used, Firestone Airmount No. 125, have a natural frequency of 160 Hz and will deflect approximately 3 in. before bottoming out. Tests were conducted with the bags pressurized at values ranging from 30 to 70 psi. Having an effective area of 11.5 in.^{2} each, or 46 in.^{2} total, the four bags could resist a load of up to 1380 lb with each bag pressurized at 30 psi and up to 3220 lb at 70 psi.

A nonoperational AN/GRC-103 transmitter and receiver was placed in the rack and the system was instrumented as in the previous tests, i.e.,

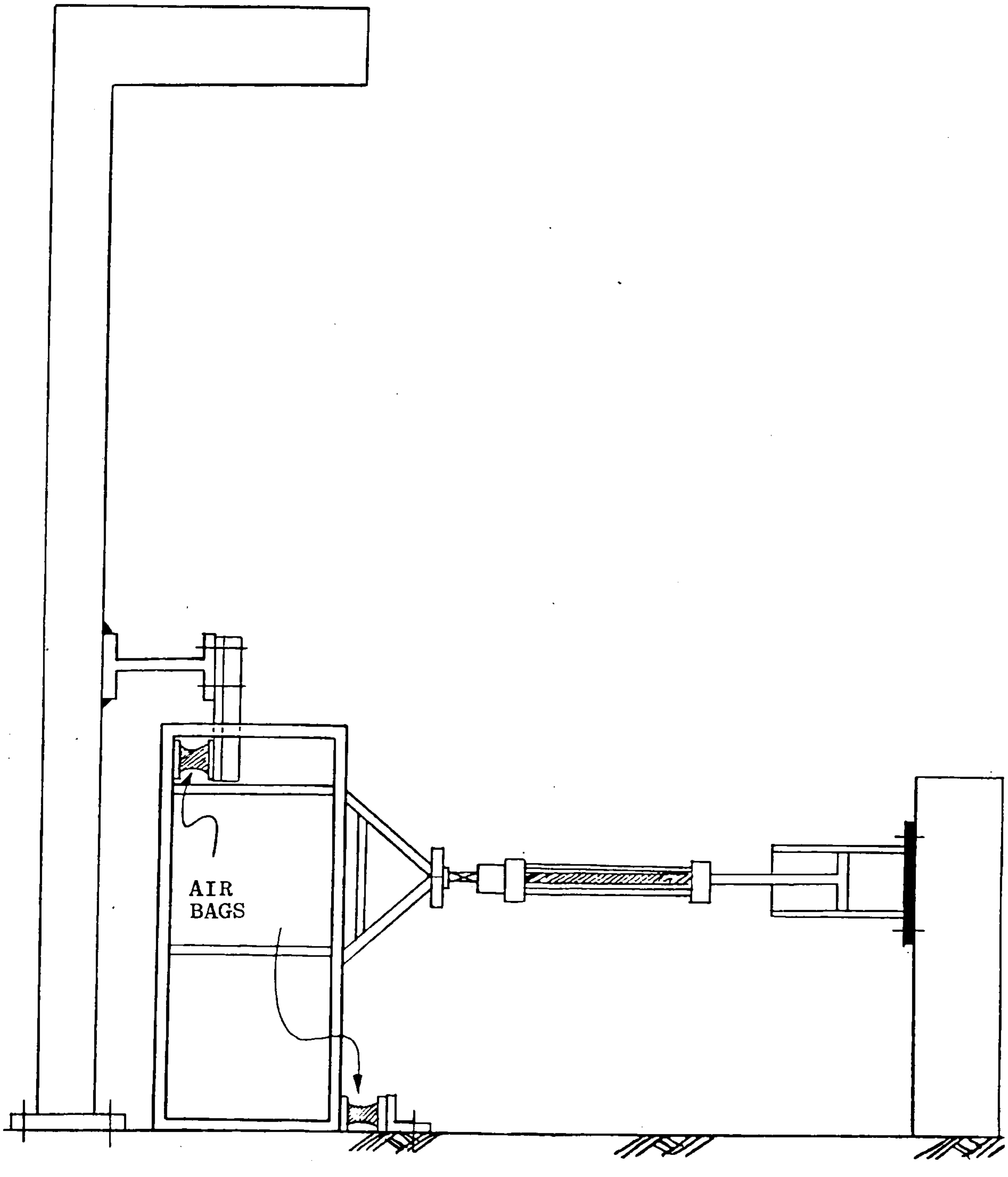


Figure 42. Schematic of "soft mount" test setup

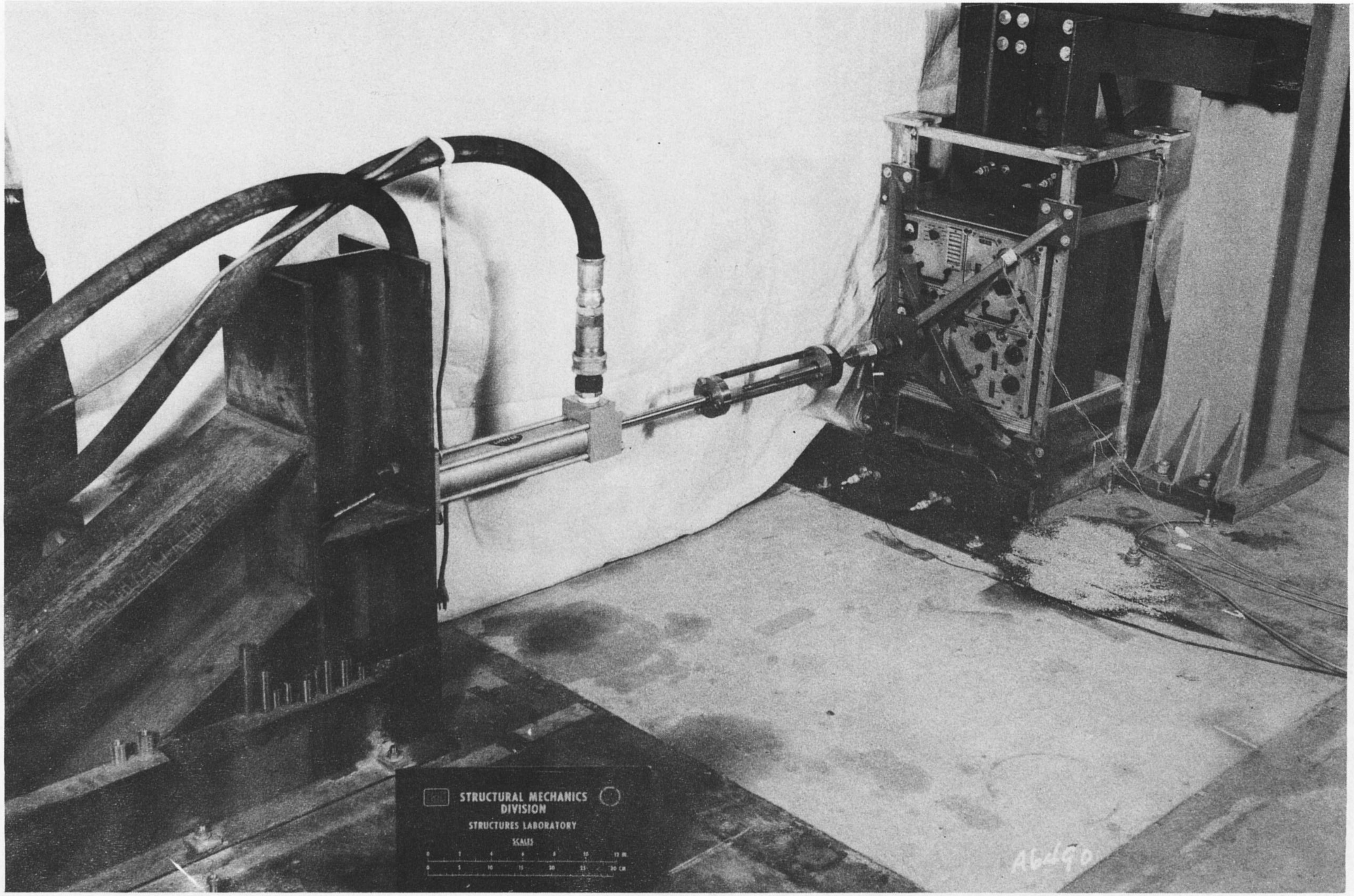


Figure 43. Soft mount test setup (view 1)

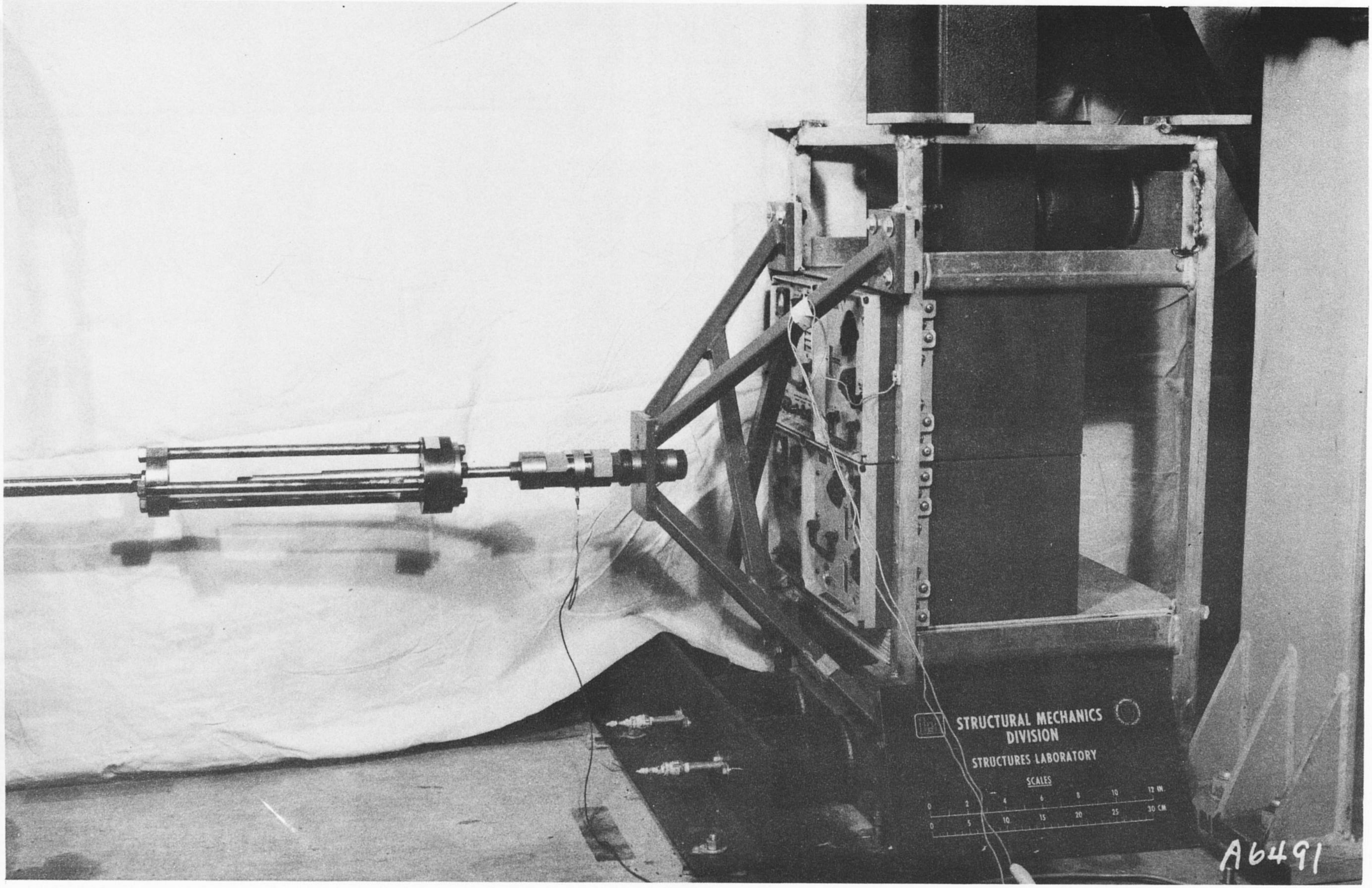


Figure 44. Soft mount test setup (view 2)

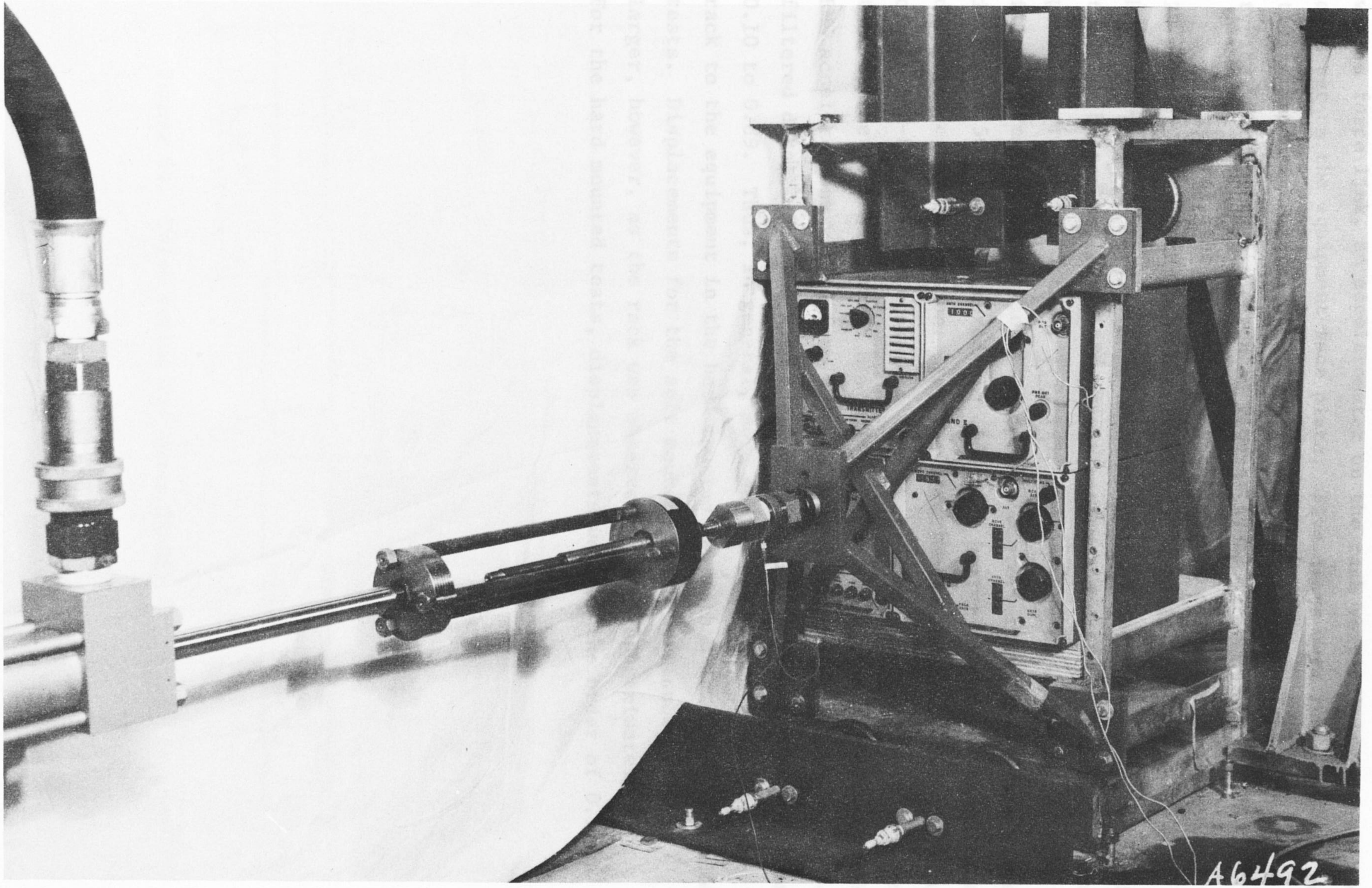


Figure 45. Soft mount test setup (view 3)

with a force link, an accelerometer on the rack vertical leg and an accelerometer on the equipment face plate. Five tests were run using the pulse trains shown in Figure 46. The data are summarized in Table 5, and typical data plots are given in Figures 47-49.

In general, the RMS values of the rack accelerations were 9 to 20 percent that of the peak acceleration. Whereas, for the equipment, the RMS values ranged from 14 to 40 percent that of the peak. Playbacks of the time histories, FFT's, and cross spectral density records using low-pass filters of 10, 5, 3.5, 2.5, 1.5, and 0.5 kHz were also made. The filtered records of the input force-time history from Test 25 are given in Figure 50. Such filtered plots offer a better picture of the frequency dependent equipment motion. For the five tests conducted, the RMS values of the 500-Hz filtered equipment acceleration ranged from 25 to 50 percent that of the 10-kHz filtered RMS values. The ratio of equipment to rack RMS accelerations varied from 0.08 to 0.16 (considering only 5- and 10-kHz filtered data). For the hard mounted tests this same ratio ranged from 0.10 to 0.89. Thus, in general, more energy was transmitted from the rack to the equipment in the hard mounted tests than in the soft mounted tests. Displacements for the soft mounted tests were substantially larger, however, as the rack was observed to move approximately 2 in. For the hard mounted tests, displacements were on the order of 0.1 in.

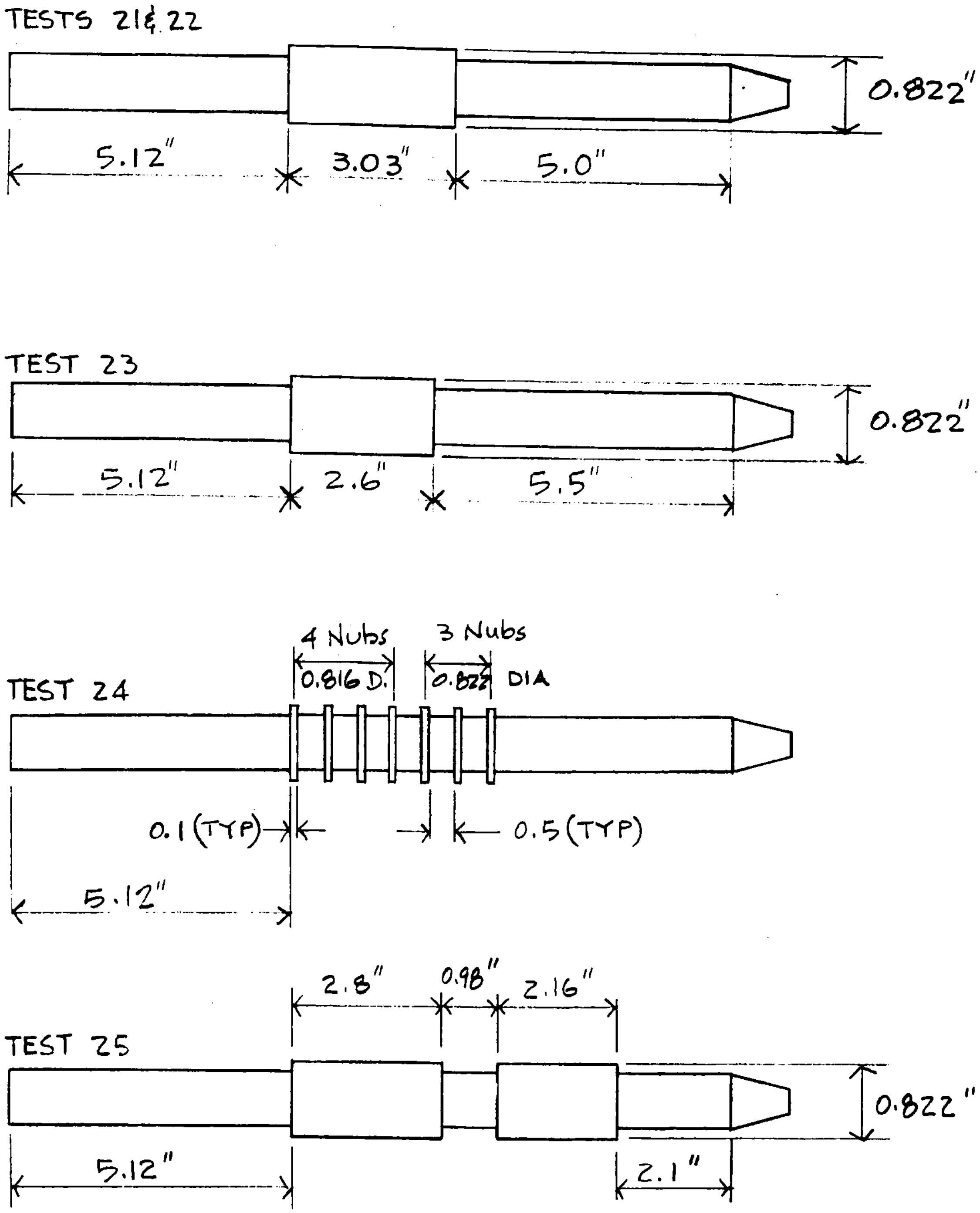
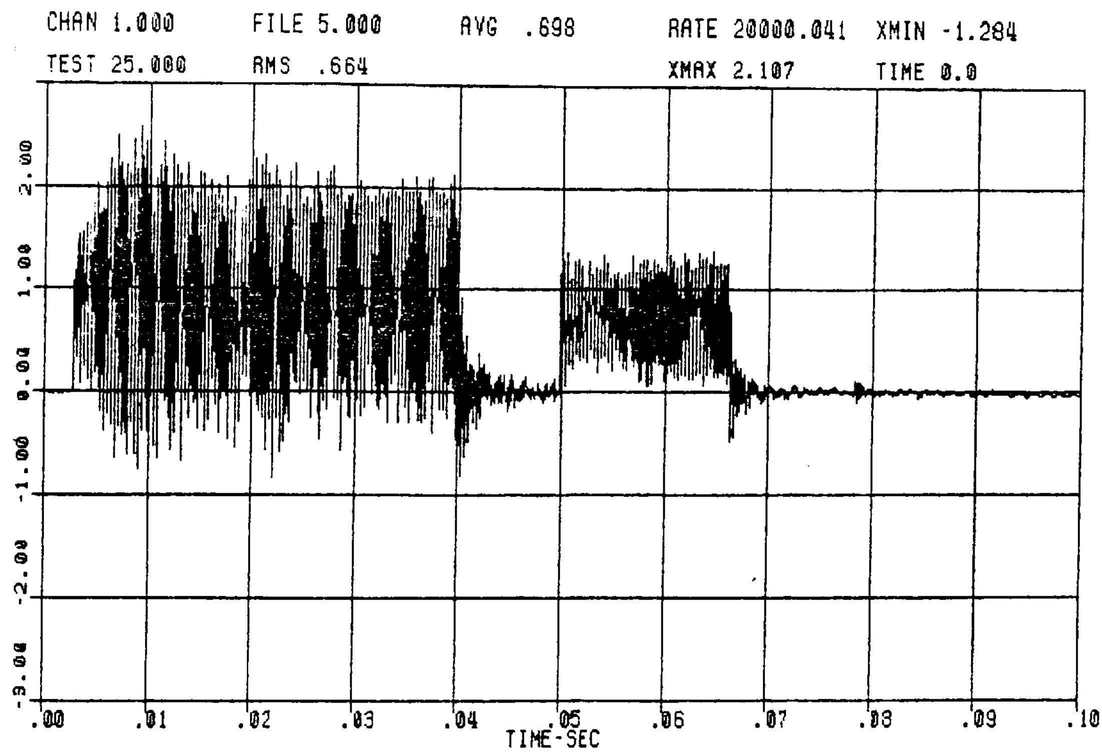


Figure 46. Pulse trains for Tests 21-25. Rack soft mounted

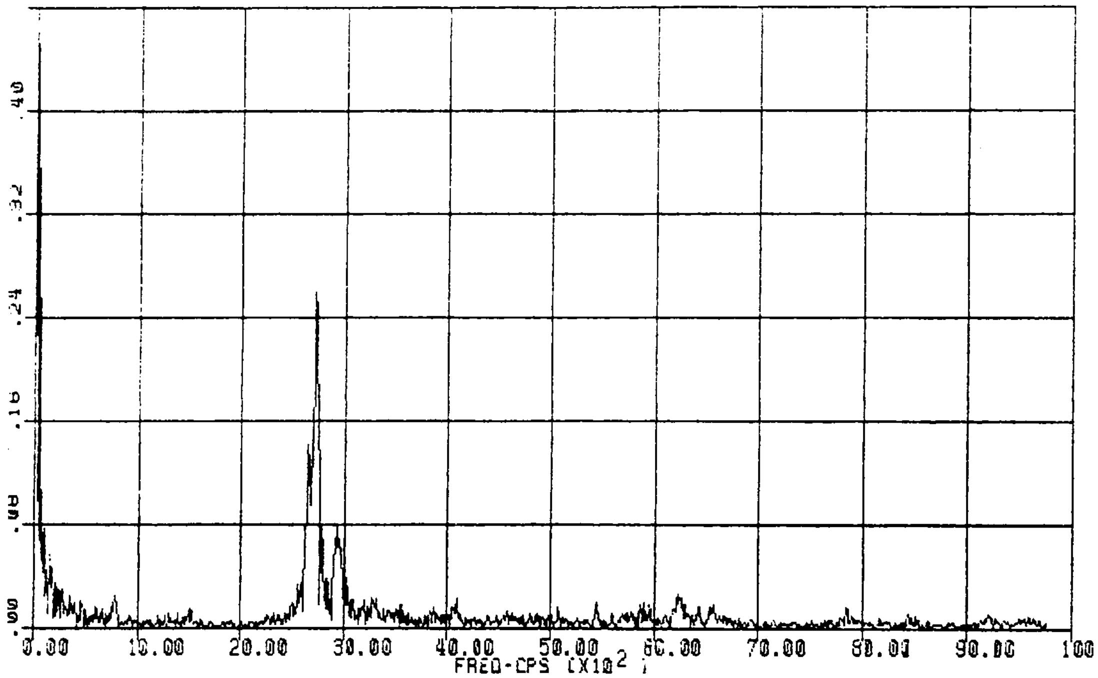
Table 5

Summary of Tests 21-25, Rack Soft Mounted on Air Bags

Test No.	Average Force (lbs)	Rack Acceleration (G)			Equipment Acceleration (G)			[EQPT/RACK] RMS	Low-Pass Filter (kHz)
		MAX	RMS	RMS/MAX	MAX	RMS	RMS/MAX		
21	900	1244	233	0.19	84	19	0.23	0.08	10
		1145	252	0.22	70	19	0.27	0.08	5
		1400	227	0.16	70	18	0.26	0.08	3.5
		1150	203	0.18	55	15	0.27	0.07	2.5
		900	177	0.20	30	9	0.30	0.05	1.5
		680	138	0.20	25	8.	0.32	0.06	0.5
22	1000	1302	203	0.16	63	16	0.25	0.08	10
		1160	210	0.18	50	16	0.32	0.08	5
		1300	192	0.15	70	15	0.21	0.08	3.5
		1100	169	0.15	30	11	0.37	0.06	2.5
		930	142	0.15	22	8	0.36	0.06	1.5
		600	102	0.18	20	8	0.40	0.08	0.5
23	1000	1252	134	0.11	98	19	0.19	0.14	10
		1100	142	0.13	90	19	0.21	0.13	5
		700	120	0.17	70	17	0.24	0.14	3.5
		650	93	0.14	38	12	0.32	0.13	2.5
		350	65	0.19	22	8	0.36	0.12	1.5
		130	31	0.24	21	8	0.38	0.26	0.5
24	1500	1221	155	0.13	99	14	0.14	0.12	10
		1200	163	0.14	80	14	0.18	0.09	5
		1500	132	0.09	70	12	0.17	0.09	3.5
		1226	107	0.09	40	8	0.20	0.07	2.5
		850	84	0.10	25	7	0.28	0.08	1.5
		320	54	0.17	15	5	0.33	0.09	0.5
25	1100	1238	184	0.15	152	29	0.19	0.16	10
		1174	191	0.16	130	28	0.22	0.15	5
		1150	160	0.14	130	27	0.21	0.17	3.5
		900	120	0.13	80	16	0.20	0.13	2.5
		700	93	0.13	22	8	0.36	0.08	1.5
		350	57	0.16	20	7	0.35	0.12	0.5

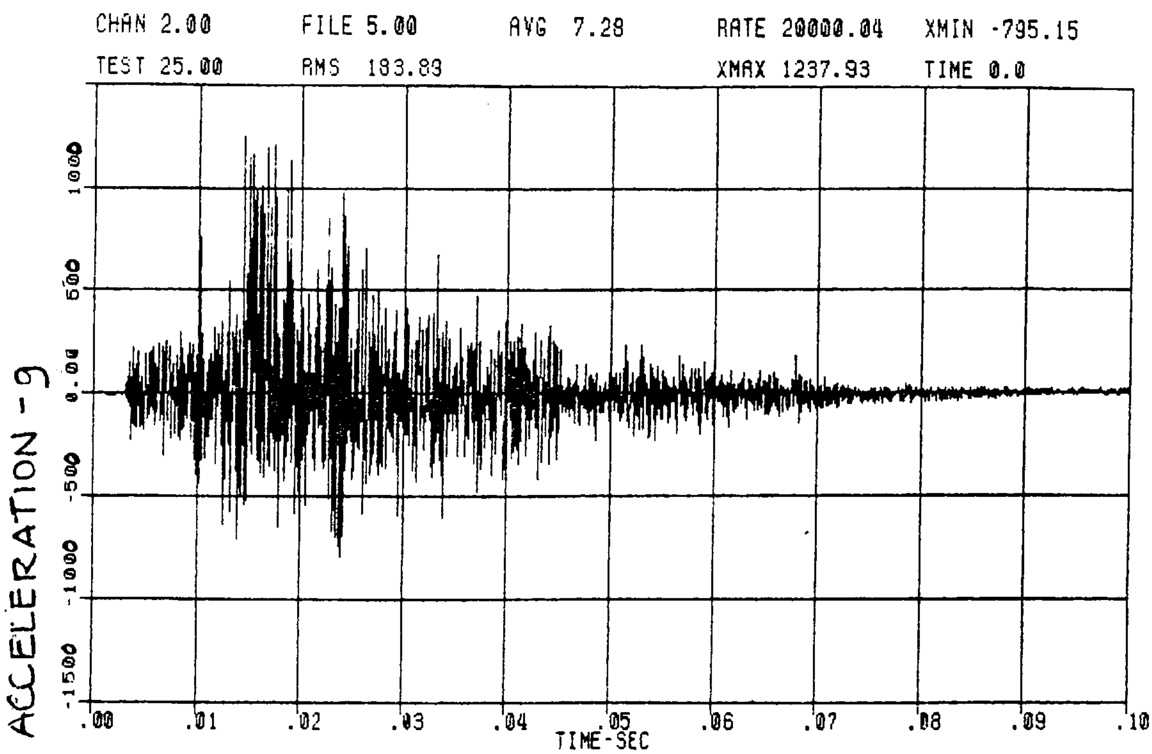


(a) Input Force Time History

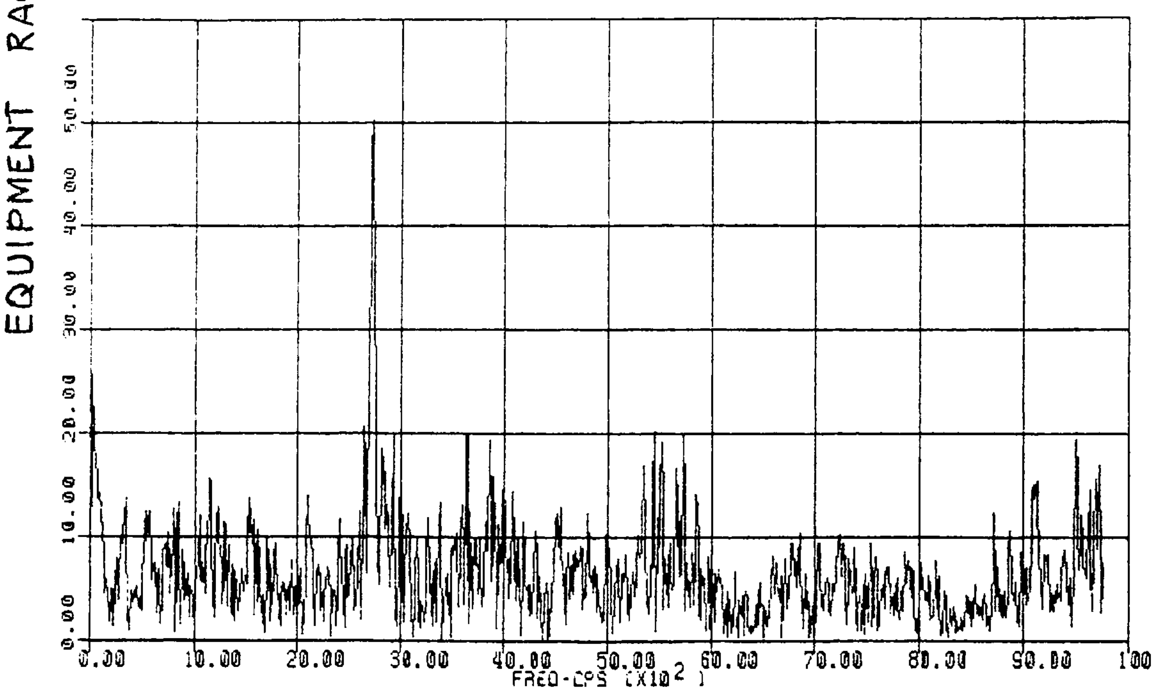


(b) FFT of Input Force Time History

Figure 47. Input force data - Test 25

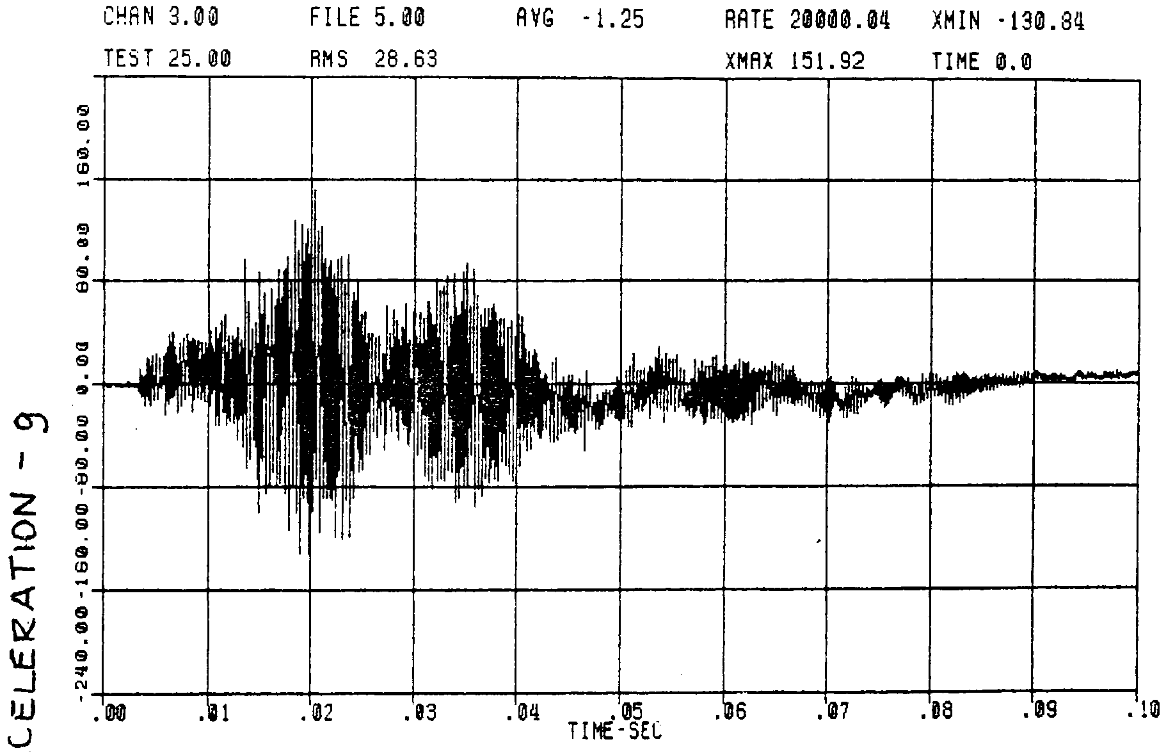


(a) Acceleration Time History

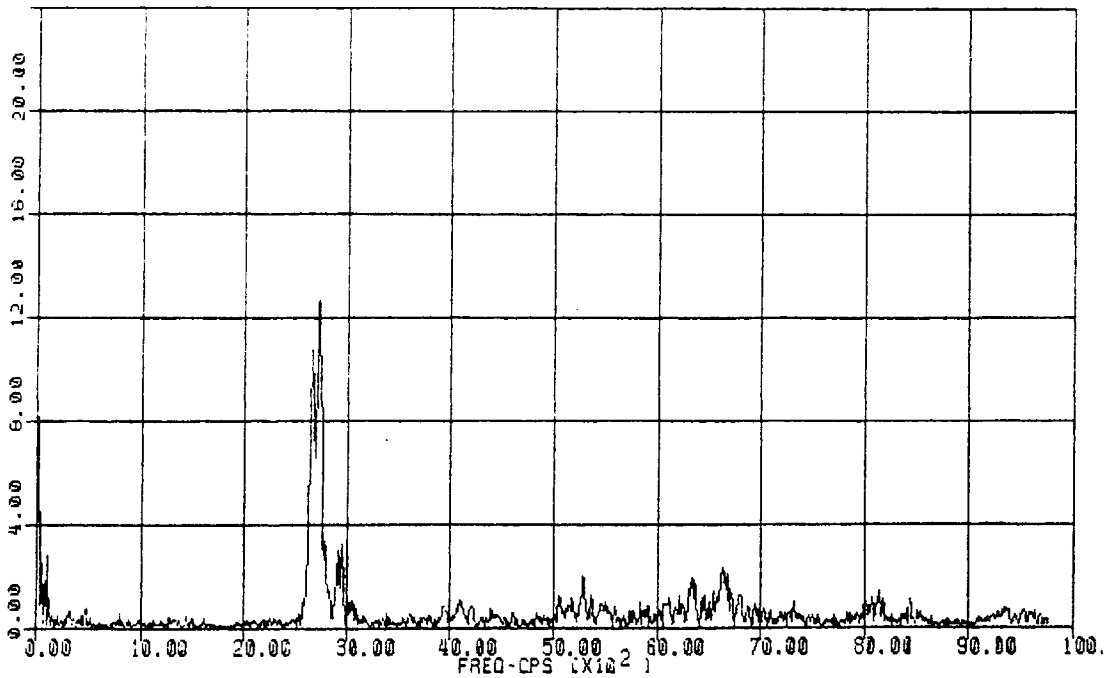


(b) FFT of Acceleration Time History

Figure 48. Equipment rack response data - Test 25

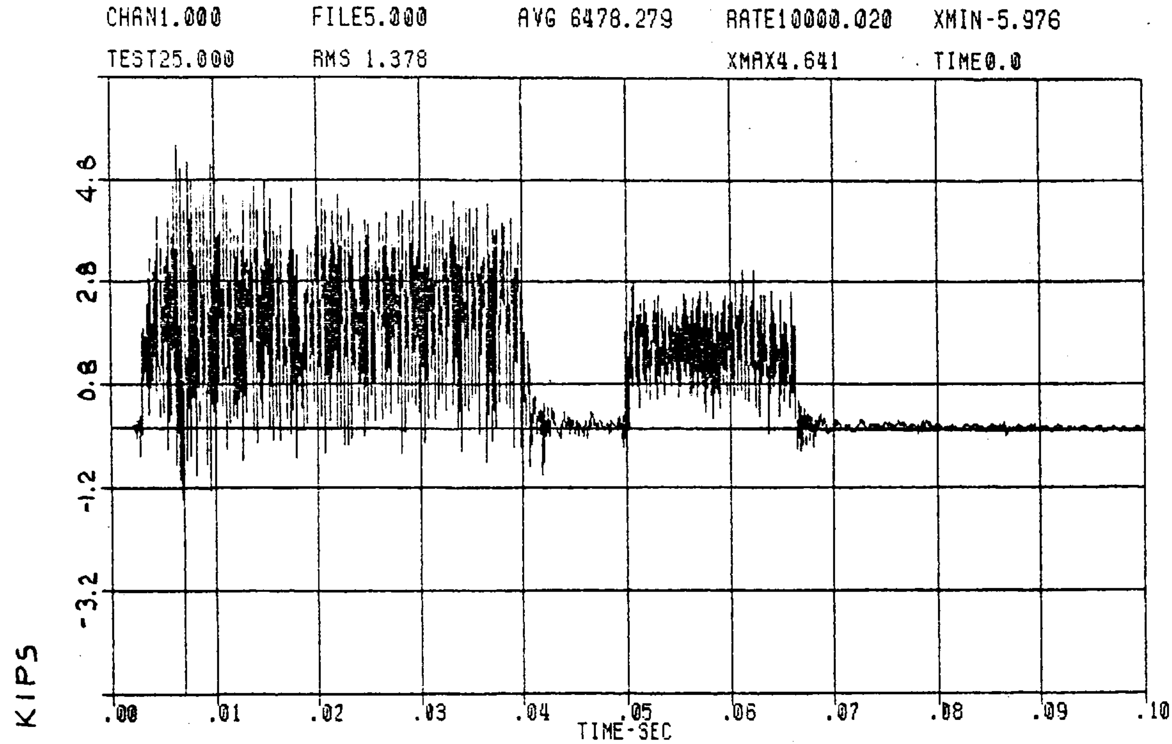


(a) Acceleration Time History

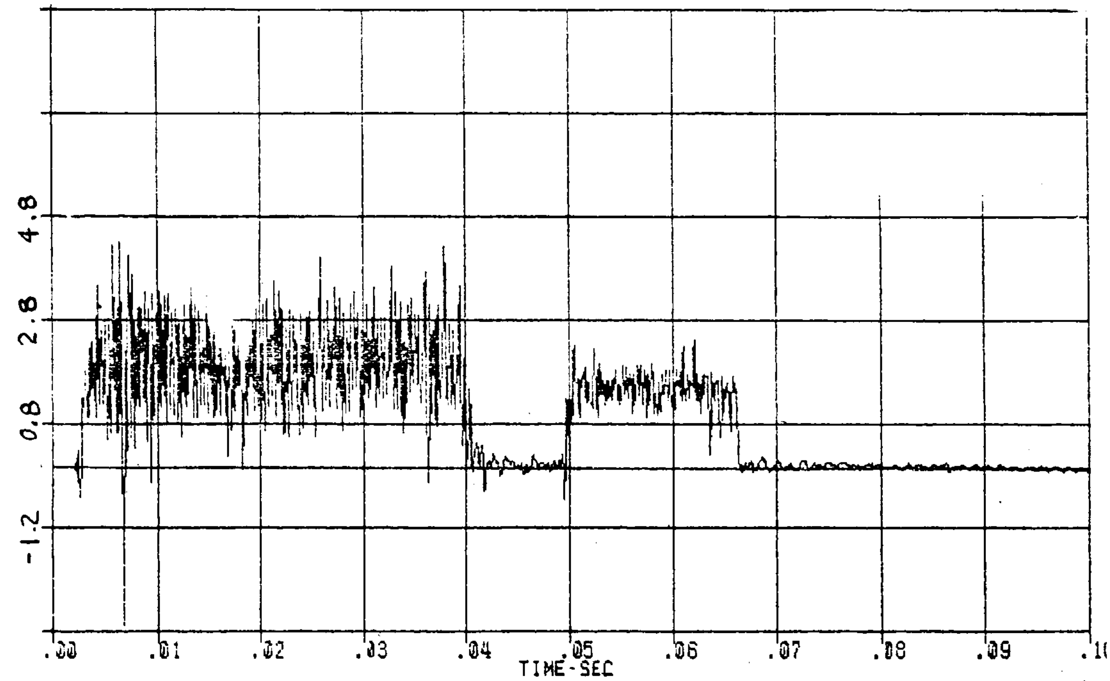


(b) FFT of Acceleration Time History

Figure 49. Equipment response data - Test 25

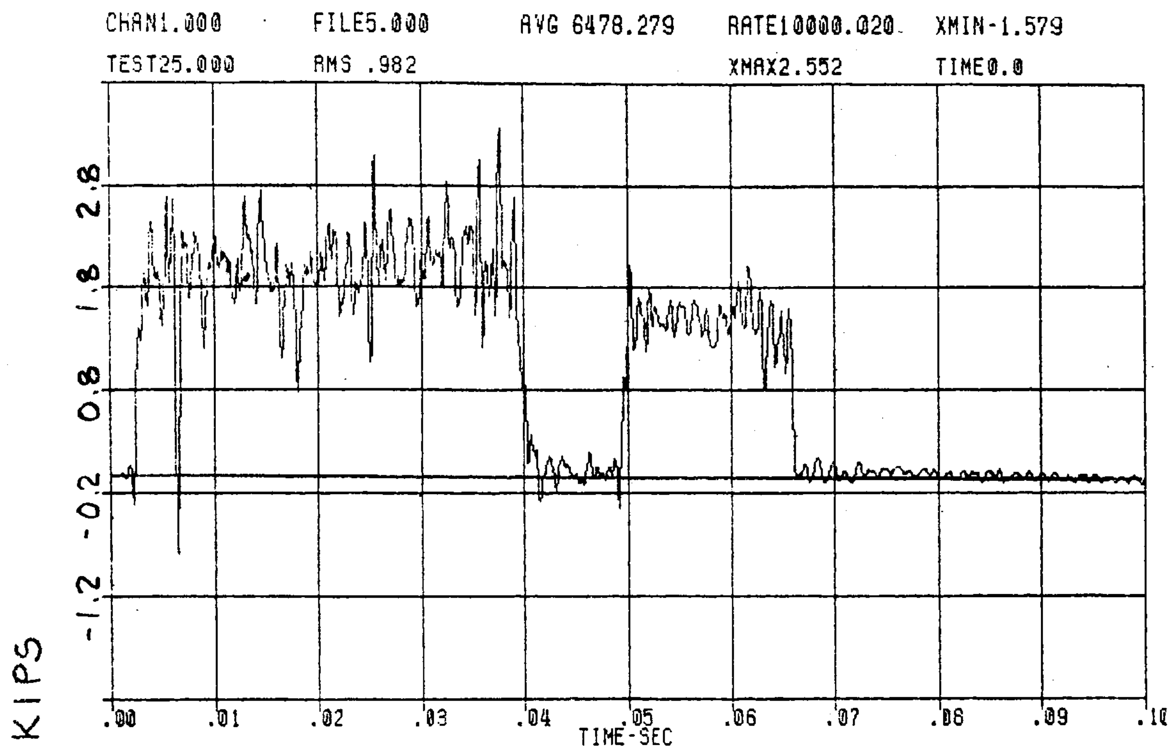


(a) 3500 Hz Low Pass Filter

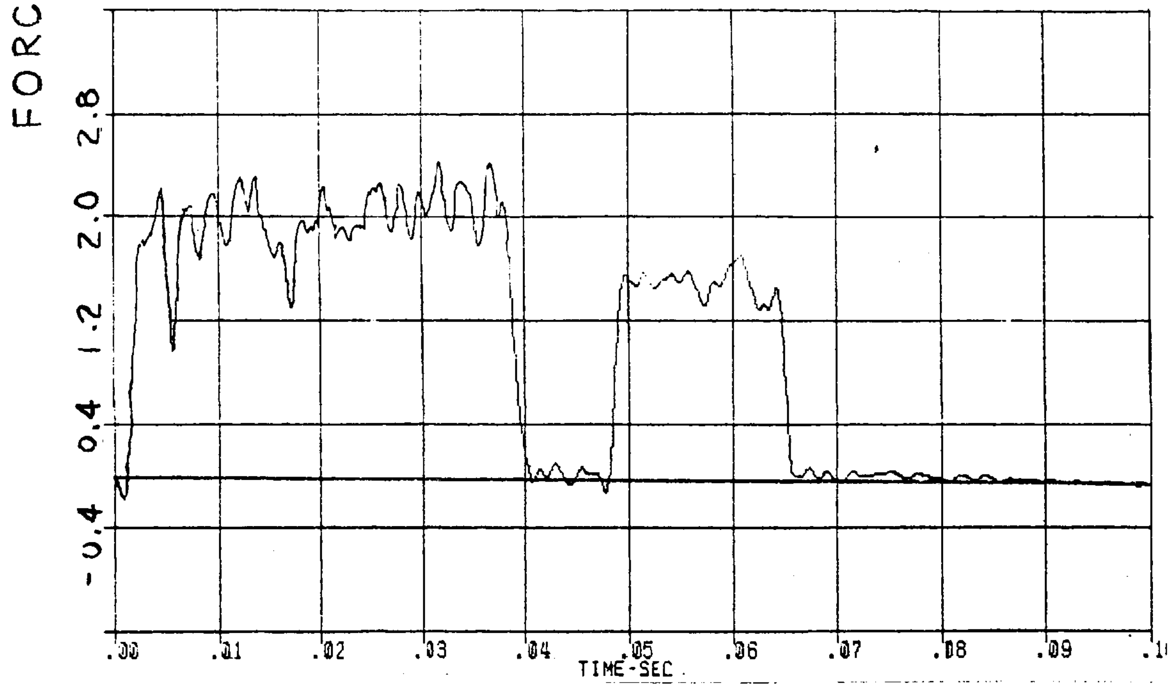


(b) 2500 Hz Low Pass Filter

Figure 50 (Sheet 1 of 2). Filtered time history data for Test 25 input force



(c) 1500 Hz Low Pass Filter



(d) 500 Hz Low Pass Filter

Figure 50 (Sheet 2 of 2). Filtered time history data for Test 25 input force

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The effort to date has been successful. A unique test device has been developed and has been shown to be an effective means for subjecting communication equipment to acceleration levels that might be encountered in a battlefield condition. Based on results of tests thus far conducted, the following conclusions are given:

1. A biaxial force-pulse generating device (pulser) has been developed which has a force output capacity of approximately 10,000 lb.
2. The pulser can be controlled to initiate simultaneous force pulses in both horizontal and vertical axes.
3. Up to 2000-g peak and 300-g RMS acceleration levels have been induced in the equipment rack with up to 200-g peak and 48-g RMS being transmitted to the equipment in the rack.
4. The AN/GRC-103 and TD660 communication equipment sustained no damage while being operated on-line during force-pulse tests which produced 200-g peak (32-g RMS) in the equipment.
5. For the pulse trains thus far used in the test program, acceleration levels measured on the equipment were 10 to 89 percent (average of 34 percent) of those measured on the rack, with the rack hard mounted, and 8 to 16 percent with the rack soft mounted on air bags (considering 5-kHz low-pass filtered data).
6. The present cutter being used in the pulser produces a certain amount of tool chatter as the aluminum nubbins are cut. This chatter results in a high concentration of force in the 2500- to 3000-Hz region. For cuts with a lesser degree of chatter the force input is more broadbanded without large concentrations of energy at particular frequencies.

REOMMENDATIONS

For a successful program of testing communication equipment with the force-pulse generator the following recommendations are offered:

1. Specific pulse trains should be designed utilizing the dynamic characteristics of the equipment and equipment rack system. Furthermore, the dynamic characteristics should be obtained from high-level excitation such as an actual force pulse test.
2. Additional development work should be done in an effort to reduce tool chatter. Areas to consider include cutter shape, depth of cut, and nubbin material. Perhaps a softer material, such as nylon, teflon, or micarta, using greater depths of cuts with the existing cutter would produce acceptable force levels with reduced chatter.
3. A realistic acceleration standard, to which the communication equipment be subjected in a laboratory test environment, should be developed. Once this standard is known, a pulse train should be designed which will result in equipment response matching the standard.

INTERNSHIP SUMMARY

The successful progress to date of the subject project represents a demonstration of meeting the stated general objectives of Chapter 1. To the satisfaction of the project sponsor the program was planned; the test device was designed, fabricated, and made operational; and the program was reported in the form of a technical report. The internee, as the WES principal investigator, assumed a direct integral position as a part of the total project team. Working with the project sponsor and a consulting engineering firm (AA) the program was planned. To succcessfully perform the tasks required of WES the internee was directly responsible for scheduling and obtaining the necessary personnel, equipment, and working space.

Utilizing these resources as available within the Structures Laboratory the project was completed within cost and time constraints.

Careful scheduling and planning was required of the internee since:

1. A suspense date had been applied to project funds.
2. Funding cuts experienced by the sponsor were passed along to WES thereby decreasing project funds.
3. An extremely heavy work load coupled with hiring restrictions created both personnel and space shortages within the Structural Mechanics Division.

The managerial abilities and adaptability of the internee were tested in dealing with such situations as those stated above. As evidenced by the success of the project the internee was able to handle the project and make management decisions in an effective manner.

To a large extent, the project management capabilities of the internee can be related directly to training received in the Doctor of Engineering Program. In particular, due to a basic understanding of fundamentals within the broad area of management coupled with advanced technical training the internee was able to handle his responsibilities with a greater awareness and perspective.

CHAPTER 4

OTHER CONTRIBUTIONS

Brief summaries of other contributions made during the subject internship are as follows:

Effects of Fuel-Air Explosive Munitions on Urban and Battlefield Structures. This project is an ongoing, multiyear study to develop criteria for determining the effects of fuel-air explosives on various types of structures. Serving as principal investigator, responsibilities included formulating a program plan of experimental and analytical study, design of various structural elements used in field tests, working with contract branch and contractor on field construction effort, supervising WES field crew during construction phase and test phase, formulating instrumentation test plan, designing gage mounts, data reduction and analysis.

Construction of Model Missile Housing Components. As part of the MX missile development, WES is conducting dynamic tests of various structural elements. In particular, reinforced concrete model cylinders simulating the missile shelter are being constructed and tested. Approximately 50 different models will be tested in 1980-1981. The models are 5 ft in height, 2-1/2 ft in diameter, with wall thicknesses ranging from 1-1/2 to 3 in. Problems were encountered while casting the earlier models stemming from insufficient vibration of the concrete. Conventional concrete form vibrators were being used. However, these units are fixed-frequency, and if the frequency happened to be near an antiresonant frequency of the form very little energy would be transmitted to concrete vibration. The forms are massive, rigid steel cylinders. Serving somewhat in a consultant capacity to the project engineer, this internee utilized electrohydraulic vibration equipment which had been used on previous dynamic investigations. Having a variable frequency control and large force capability, the vibrator was tuned to the resonant frequency of the form. Excellent model castings with no voids have been the result.

Research Proposals. Since WES is not funded by appropriation, but rather is supported on a cost reimbursable basis, proposals are a viable and important aspect of a WES engineer's duties. Two proposals were prepared by this internee during the subject internship. An Equipment Shock Fragility proposal was submitted to the Office, Chief of Engineers, as part of military funded research and a Tainter Gate Study proposal was submitted to the Savannah District, at their request, in response to a vibration problem at Clark Hill Dam.

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8. Schuman, W. J., et al., "Biaxial Transient Simulation Tests for Communications Equipment to Match High Explosive Field Test Records," 6th International Symposium on Military Application of Blast Simulation, June 25, 1979, Center d'Etudes de Gramat, Cahors, France.
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11. Agbabian Associates, "Impedance-Based Motion Prediction, Scaling, and Environmental Simulation for Shock Applications," Naval Research Laboratory Memorandum Report 3676, Dec 1977.

APPENDIX I

ORGANIZATIONAL STRUCTURE, MISSIONS, AND JOB DESCRIPTIONS

A. JOB DESCRIPTION-RESEARCH STRUCTURAL ENGINEER (GS-12)

DEPARTMENT OF THE ARMY **JOB DESCRIPTION**	1. INSTALLATION OR HEADQUARTERS OFFICE U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi	2. JOB NUMBER 4192(E)

3. CITATION TO APPLICABLE STANDARD AND ITS DATE OF ISSUANCE CSC Position Classification Standards GS-810-0, dtd Dec 64 EXEMPT	4. TITLE Research Structural Engineer		
	5. PAY SCHEDULE GS	6. OCC. CODE 810	7. GRADE 12
8. EVALUATION APPROVAL Title, pay schedule, code and grade of this job have been fixed in accordance with Department of the Army official policy and grade level standards.	SIGNATURE G. A. Wilkerson G. A. WILKERSON		DATE 25 FEB 1974

9. SUPERVISORY CONTROLS, DUTIES, AND WORKING CONDITIONS *(Indicate percent of time for each duty, where pertinent.) (Continue statement of duties, etc., on reverse side if necessary.)*

SUPERVISORY CONTROLS

Works under general supervision of Division Chief and/or Project Manager. Receives assignments of projects and problems related to a specific area of protective construction with instructions for general approach, plan of work, objectives, schedules, priorities, etc., developed by supervisor and the incumbent. Takes initiative to develop and execute specific work plans and to obtain and present required results applying own knowledge, experience and judgment, and making full use of the technical literature. Consults with supervisor and professional associates to obtain benefit of related specialized knowledge, guidance, or group judgment as appropriate. Work is reviewed for attainment of satisfactory results.

MAJOR DUTIES

1. As a project engineer develops, coordinates, and carries through to completion blocks of work of large scope containing many phases of which two or more phases each contain several complex features. Many of the duties are concerned with planning and coordinating the various phases as performed by other technical personnel, reviewing each phase as completed, and maintaining liaison for coordinating and conducting investigations to determine the response and performance of structural systems and components subjected to static and dynamic loads. In addition, shares with other project engineers the responsibliity to conduct similitude investigations and determine the feasibility of using model techniques to predict the response of structures subjected to dynamic loads. Performs the following typical duties:

   a. Extensive review of the technical literature to keep abreast of current developments, to obtain all available information, and to discover voids in existing information and data pertaining to broad objectives of the projects.

10. **JOB CONTENT APPROVAL** *(Complete on organization file copy only.)*

ORGANIZATION LOCATION
Weapons Effects Laboratory, Structures Division, Research Projects Group

THIS STATEMENT ACCURATELY DESCRIBES THE WORK REQUIRED IN ONE POSITION OR IN EACH OF A GROUP OF POSITIONS IN THE ABOVE ORGANIZATION.	THE ABOVE DESCRIPTION, WITH SUPPLEMENTAL MATERIAL, IS ADEQUATE FOR PURPOSES OF EVALUATION.
SIGNATURE OF APPROVING SUPERVISOR	SIGNATURE OF ANALYST

11. **REAUDIT APPROVAL**

DATE								
SUPERVISOR'S APPROVAL								
ANALYST'S SIGNATURE							201	FILE COPY

b. To utilize computer facilities, as necessary, and to develop computer programs for conducting theoretical analyses, for reducing data, and for analyzing results of tests.

c. Preparing proposals for work within the scope of assigned projects, which include the objective(s) of the work, the scope, the method of approach, sufficient background information to justify need, and time and cost estimates.

d. Makes trips and confers with representatives of other interested government agencies in the planning and arranging of tests for the mutual benefit of all concerned. Makes progress reports to show status of projects.

e. Serves as project coordinator and/or officer representing the Station on joint undertakings of government agencies in conducting full or model-scale tests of weapons effects.

f. Prepares interim and final reports involving evaluation and analysis of data collected and correlation of data with those from other agencies.

Plans and theoretical analysis as well as

g. conducts model and prototype tests of protective and other structures subjected to dynamic loads such as those produced by nuclear and conventional weapons, demolitions, and earthquakes. Tests may be conducted using laboratory facilities, such as blast generators and dynamic loading devices or at remote explosive test sites or prototype facilities.

2. Performs limited administrative and supervisory duties appropriate for the work assigned; assigns and instructs subordinate employees; checks on performance for quality of work and rate of progress; makes or reviews performance appraisals of subordinate employees; is responsible for knowledge and observance of all safety rules and regulations as they apply to the work described.

Performs other duties as assigned.

B. JOB DESCRIPTION - RESEARCH STRUCTURAL ENGINEER (GS-13)

DEPARTMENT OF THE ARMY
JOB DESCRIPTION
For use of this form, see CPR 501; the proponent agency is DCSPER.

1. JOB NUMBER: 5501

2. INSTALLATION OR HEADQUARTERS OFFICE
U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

3. ORGANIZATIONAL LOCATION *(Complete on organization copy only)*
Structures Laboratory, Structural Mechanics Division, Research Group

4. CITATION TO APPLICABLE STANDARD AND THE DATE OF ISSUANCE
OPM, Position Classification Standards, GS-810, dtd Dec 64 & Research Guide

5. TITLE
Research Structural Engineer

6. PAY SCHEDULE	7. OCC CODE	8. GRADE
GS	810	13

9. FAIR LABOR STANDARDS ACT: ☒ EXEMPT ☐ NONEXEMPT

10. COMP LEVEL: 038

11. EVALUATION APPROVAL

TITLE, PAY SCHEDULE, OCC CODE, AND GRADE OF THIS JOB HAVE BEEN FIXED IN ACCORDANCE WITH OFFICIAL POLICY AND GRADE LEVEL STANDARDS

R.W. Pigg
R. W. PIGG *(Signature)*

7/8/80 *(Date)*

12. JOB CONTENT APPROVAL *(COMPLETE ON ORGANIZATION COPY ONLY)*

a. I CERTIFY THAT THIS IS AN ACCURATE STATEMENT OF THE MAJOR DUTIES AND RESPONSIBILITIES OF THIS POSITION AND ITS ORGANIZATIONAL RELATIONSHIPS AND THAT THE POSITION IS NECESSARY TO CARRY OUT GOVERNMENT FUNCTIONS FOR WHICH I AM RESPONSIBLE. THIS CERTIFICATION IS MADE WITH THE KNOWLEDGE THAT THIS INFORMATION IS TO BE USED FOR STATUTORY PURPOSES RELATING TO APPOINTMENT AND PAYMENT OF PUBLIC FUNDS AND THAT FALSE OR MISLEADING STATEMENTS MAY CONSTITUTE VIOLATIONS OF SUCH STATUTES OR THEIR IMPLEMENTING REGULATIONS.

James T. Ballard
(Signature of Approving Supervisor)

7 July 1980 *(Date)*

b. THIS JOB DESCRIPTION WITH SUPPLEMENTAL MATERIAL IS ADEQUATE FOR PURPOSE OF EVALUATION.

R.W. Pigg
(Signature of Position Classification Specialist)

7/8/80 *(Date)*

13. STATEMENT OF DUTIES AND RESPONSIBILITIES

SUPERVISORY CONTROLS

Works under general supervision of the Division Chief. Receives assignment of projects and problems related to a specific area of protective construction with instructions for general approach, plan of work, objectives, schedules, priorities, etc. Takes initiative to develop and execute specific work plans and to obtain and present required results applying own knowledge, experience, and judgment, and making full use of technical literature and consultant's services. Consults with supervisor and professional associates to obtain benefit of related specialized knowledge, guidance, or group judgment as appropriate. Occupies a significant place in the subject field work; accomplishments are therefore of some note and must have professional acceptance accordingly. Work is reviewed for attainment of satisfactory results.

MAJOR DUTIES

1. As a leader of a research team, has responsibility for planning and prosecution of long-range research and development studies and for formulating and conducting systematic research studies on structures subjected to the effects of nuclear and conventional weapons and other dynamic loads, e.g., research programs for DNA and

other organizations concerning strategic structures and/or elements of strategic systems as well as basic studies that provide input to a wide variety of protective systems. Studies may be carried out by the incumbent or by a group of which the incumbent is the manager. Is responsible for initiating and performing theoretical studies both in-house and under contract, performing theoretical analyses, keeping abreast of the state-of-the-art in the field of protective structures, response of structures to earthquakes, conducting complex laboratory experiments, and writing technical reports. Current projects deal primarily with work sponsored by the Defense Nuclear Agency, Office, Chief of Engineers, Space and Missile Systems Organization, DoD, etc. The following are examples of typical duties:

a. Extensive review and evaluation of technical literature to keep abreast of current developments, to obtain all available information to discover voids in existing information, and to determine the impact of this literature in respect to the broad objectives of the projects.

b. To utilize computer facilities, as necessary, and to develop computer programs for conducting theoretical analyses, for reducing data, and for analyzing results of tests.

c. Prepares proposals for work within the scope projects under his management which include the objective(s) of the work, scope, method of approach, sufficient background information to justify need, and time and cost estimates.

d. Makes trips and confers with representatives of other interested Government agencies in the planning and arranging of tests for the mutural benefit of all concerned. Makes progress reports to show status of projects. In addition, attends conferences to assist in the formulation of plans for future work.

e. Serves as a technical project coordinator and/or officer representing the Waterways Experiment Station on joint undertakings of Government agencies in conducting full- or model-scale tests of structures subjected to dynamic loads.

f. Prepares interim and final reports involving evaluation and analysis of data collected and correlation of data with those from other agencies.

g. Directs and/or conducts scale-model tests of weapons and other dynamic effects. This involves the same concepts and principles of the foregoing using conventional explosives, and establishing relationships between model- and full-scale conditions. Directs and conducts similar tests using blast generators and other dynamic loading devices to simulate weapons effects on buried structures and structural elements.

Job #5501

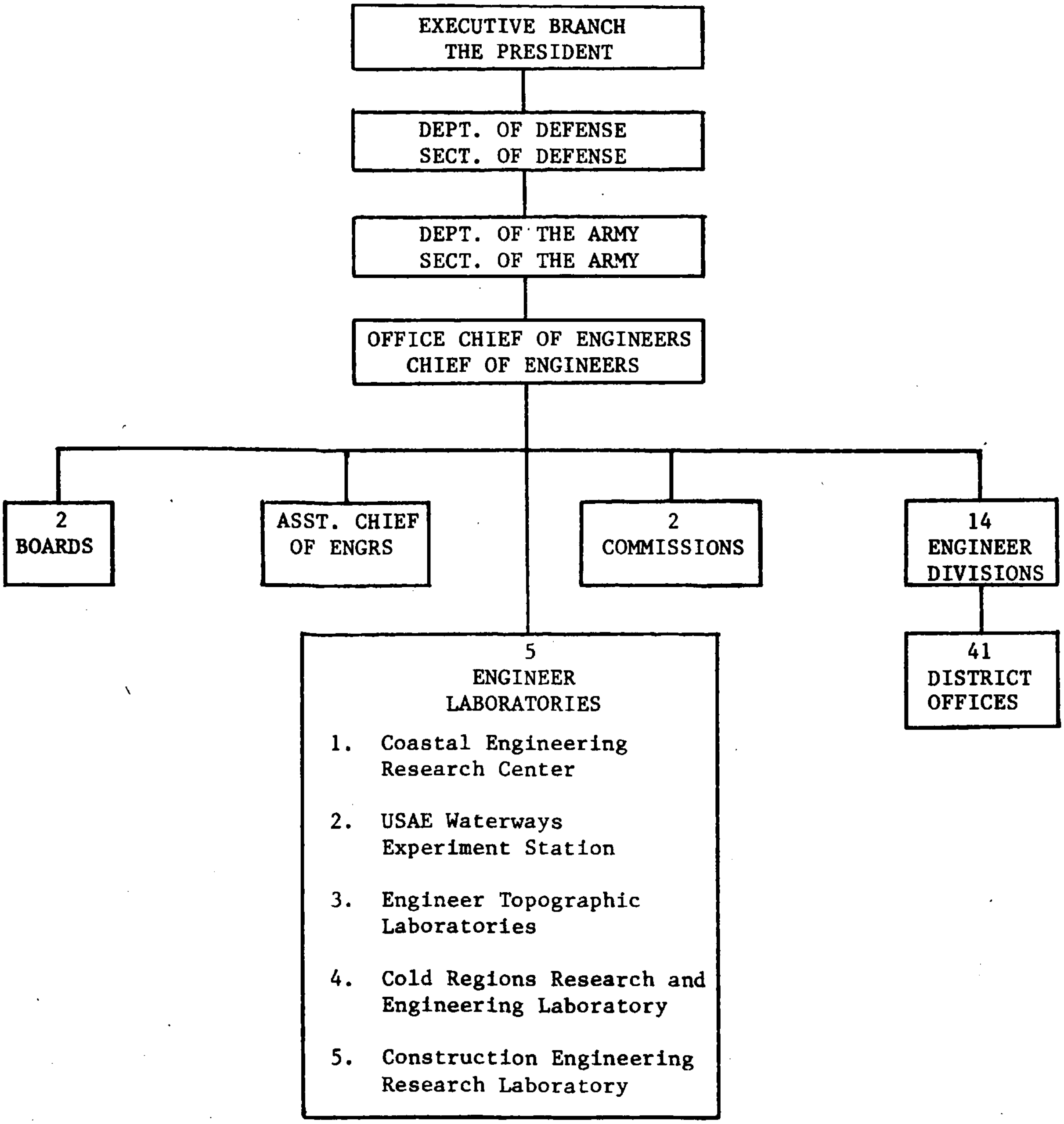
h. Directs activities of the project engineers working under his supervision to (1) make pertinent literature searches and office studies; (2) to employ such contractors as appropriate for special purposes; (3) to collect, organize, integrate, analyze information and data from all sources and prepare reports thereon, as required by sponsoring agencies; and (4) prepare project proposals, budgets, and project reports.

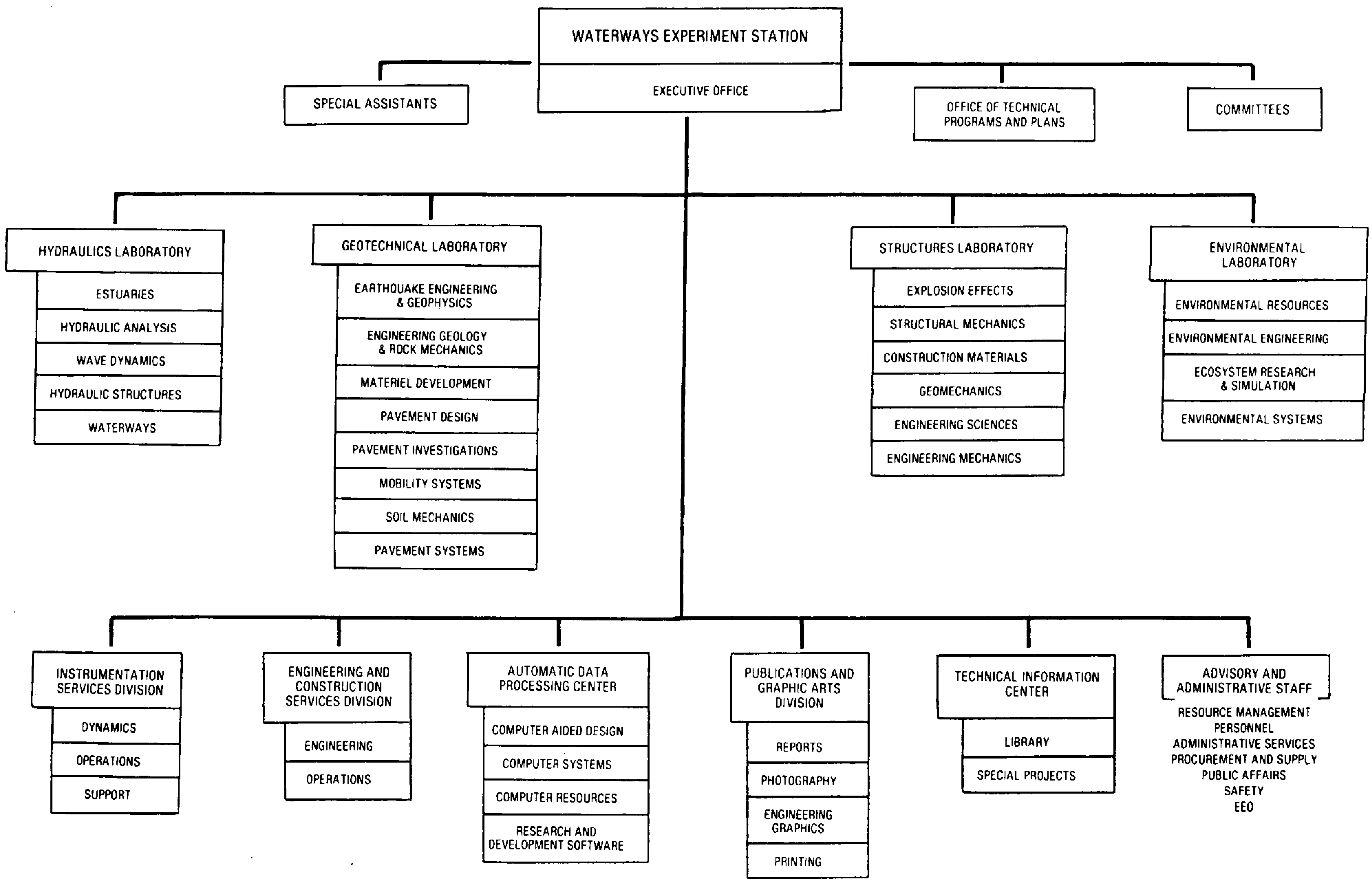
2. Performs supervisory and limited administrative duties appropriate for the work under his management; assigns and instructs subordinate employees; checks on performance of quality of work and rate of progress; makes or reviews performance appraisals of immediate subordinate employees; is responsible for knowledge and observations of all safety rules and regulations as they apply to the work described.

Performs other duties as assigned.

This position meets the requirements of AR 600-50, Standards of Conduct, therefore, Statement of Employment and Financial Interests is required.

C. ABBREVIATED ORGANIZATION CHART - U. S. ARMY CORPS OF ENGINEERS





D. ORGANIZATION CHART - WES

E. MISSION - WATERWAYS EXPERIMENT STATION

Conceive, plan, and execute engineering investigations, and research and development studies, in support of the civil and military missions of the Chief of Engineers and other Federal agencies, through the operation of a complex of laboratories in the broad fields of hydraulics, soil mechanics, concrete, engineering geology, rock mechanics, pavements, expedient construction, nuclear and conventional weapons effects, protective structures, vehicle mobility, environmental relationships, aquatic weeds, water quality, dredge material research, and nuclear and chemical explosives escavation.

Participate with the Energy Research and Development Administration (ERDA) in joint research and development through the Lawrence Livermore Laboratory and other ERDA agencies to develop nuclear engineering and construction technology; provide technical advice and assistance on use of nuclear explosives and large-yield chemical explosives to the Corps of Engineers and other Government agencies.

Provide scientific and engineering computer services and specialized instrumentation development and application to the Corps of Engineers.

Operate the Engineering Computer Programs Library for the Corps of Engineers.

Operate for the Corps of Engineers a central scientific and engineering research library with emphasis on technical fields relevant to its primary responsibilities.

Operate the Department of Defense Information Analysis Centers for pavements and soil trafficability, soil mechanics, hydraulic engineering, and concrete technology.

Assure technical adequacy of the work of other Corps of Engineers hydraulic laboratories.

Conceive, plan, and conduct training courses in assigned technical fields for Corps personnel as directed by the Chief of Engineers.

Support the Mississippi River Commission/Lower Mississippi Valley Division by providing: division soils, concrete, and materials laboratory services; division level computer services and support; field printing plant operations; and other services as requested.

Provides, upon request, support for updating Corps of Engineers specifications, technical manuals, and other criteria documents within assigned areas.

F. MISSION AND FUNCTIONS - STRUCTURES LABORATORY

MISSION

The Structures Laboratory is responsible for conceiving, planning, and executing scientific and engineering investigations and research and development projects in support of the civil and military missions of the Chief of Engineers and other Federal agencies, in the broad fields of structures, weapons effects, earth dynamics, and construction materials by establishing and maintaining staff and facilities for research, development, testing, and evaluation as related to design and analysis of structures to resist static and dynamic loading; defining free-field effects produced by the detonation of explosives; development of useful applications of explosives; evaluation of materials properties, applications, and behavior in service; and defining the state of stress in soil and rock masses especially as associated with transient loadings.

FUNCTIONS

The Structures Laboratory plans, manages, conducts, and coordinates research and development efforts to determine:

1. Response and vulnerability of structures both above and below ground to effects of static and dynamic loads including the interface environment between a buried or partially buried structure and the surrounding soil.

2. Effectiveness of survival measures and plans for the civilian population and CONUS military personnel pertaining to the effects of nuclear weapons.

3. Effects of explosions including airblast, ground shock, fragmentation, radiation, water shock, water surface waves, production of craters and ejecta, for explosions in air, underground, or underwater.

4. Free-field effects of detonations on such targets as earth and rockfill dams, airfield pavements, and tunnels.

5. Properties and behavior of a wide variety of construction materials, both singly and in combinations in composite systems such as

hydraulic-cement concrete and in structural elements and structures. The constituents of hydraulic-cement concretes, mortars, grouts; plastics and adhesives; polymers and reinforcing materials, bonding and jointing materials; coatings and curing materials; stone and rock included.

6. States of stress and deformation in earth or rock masses.

Develops analysis and design procedures for:

1. Structures such as concrete dams, navigation locks, intake towers, and retaining walls taking account of effects due to earthquakes, wind, impact, vibrations, temperatures, and materials response such as creep, shrinkage, and expansion.

2. Hardened and nonhardened structures with reference to vulnerability to nuclear and conventional weapons effects including protective structures and field fortifications.

3. Use of explosive excavation for military and civilian purposes such as creation of barriers, craters, drainage ditches, and canals, and demolition of existing structures such as levees.

4. Assessing the condition of existing structures so as to evaluate the need for modification or rehabilitation to insure safety and serviceability.

Develops procedures and criteria for:

1. Demolition of existing structures using standard and nonstandard explosives and other means.

2. Shock isolation and vibration control relating to critical components in hardened and nonhardened structures.

3. Physical and mathematical modeling, testing, evaluation of structural systems, components, and materials to static and dynamic loadings, temperature and moisture changes, environmental and other chemical attack, and spontaneous internal time-dependent phenomena.

Provides to Division and District Corps of Engineers offices and other DOD offices such as SHAPE and EUD, consulting services in its area of responsibility especially in the fields of:

1. Structural design and analysis.

2. Use of explosives for blasting, excavation, and demolition including safety aspects and hazard reduction.

3. Quantitative descriptions of a given explosion effects analysis.

4. Evaluation of construction materials in connection with planned new construction and in connection with performance of construction in service.

Operates a variety of testing and analysis facilities including:

1. Blast Load Generator
2. Fragmentation Simulation Facility
3. Big Black Test Site
4. WES Explosives Storage Area and TNT Casting Plant
5. Treat Island, Maine, severe weathering, meantide, exposure station
6. Prototype Concrete Batching and Mixing Plant
7. 2.4 million pound (force) universal testing facility

Manages major operations related to its field of responsibility including:

1. Explosives tests for DA, DNA, Navy, AF, and others.
2. Sampling and testing of hydraulic cements and pozzolans at points of production, distribution, and use for all Federal construction agencies in accordance with ER 1110-1-8100 and ER 1110-1-2002.

Conducts training courses and symposia in its area of responsibility for the OCE, Department of Defense (DOD), and the profession.

Serves as Division Concrete and Materials Laboratory for the Lower Mississippi Valley Division and Mississippi River Commission.

Operates DOD Concrete Technology Information Analysis Center.

Develops procedures, including computer software to accomplish the functions required in support of its mission. Prepares manuals, data compilations, guide specifications, Engineer Technical Letters, handbooks of authorized test methods and practices, and other technology transfer documents as appropriate.

VITA

NAME: Roger Dale Crowson

DATE OF BIRTH: November 27, 1949

PLACE OF BIRTH: Slaton, Texas

PARENTS: Clifford Julius Crowson and Leila Surratt Crowson

EDUCATION: Bachelor of Science in Civil Engineering from the University of Alabama, 1972. Master of Science in Engineering Mechanics from Mississippi State University, 1978.

PERMANENT ADDRESS: 107 Redbud Circle
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EXPERIENCE: 1972-1981 Research Structural Engineer, Structures Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. This position involves applied research and consultant services in broad fields of both civil and military oriented engineering applications. Full-time graduate study at Texas A&M University during 1978-1979 was funded by the U. S. Army's Advanced Training for Engineers and Scientists program.

1981- Interdisciplinary Engineer, Project Management Branch, Engineering Division, U. S. Army Engineer Division, Europe, Frankfurt Germany. This is a project management position in the design and construction of military projects.

The typists for this report were Brenda Young and Ann Johnson.